VOLUME V. NUMBER 6

THE JOURNAL
OF
THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

EDITOR

C. A. CHANT
University of Toronto, Toronto

ASSOCIATE EDITORS

W. F. KING
Chief Astronomer
Ottawa

R. F. STUPART
Director of the Meteorological Service of Canada, Toronto

J. S. PLASKETT
Dominion Observatory
Ottawa

PUBLISHED BI-MONTHLY

NOVEMBER-DECEMBER, 1911

PRINTED FOR THE SOCIETY
TORONTO: 198 COLLEGE ST.
FOREIGN AGENTS: WILLIAM WESLEY & SON,
28 ESSEX T., STRAND, LONDON.

THE JOURNAL

OF THE

ROYAL ASTRONOMICAL SOCIETY

OF CANADA

VOL. V. NOVEMBER DECEMBER, 1911. No. 6

Spectroscopic and Visual Binaries; An Outline of Work Done in this Field and an Indication of Its Importance	*Reynold Young*	355
A Note on φ Persei	*J. B. Cannon*	372
The Orbit of ω Ursæ Majoris	*T. H. Parker*	377
Errors in the Measurement of Spectral Line Displacements	*Ralph E. DeLury*	384
Mars: The Planet of Mystery	*C. A. Chant*	408
Meetings of the Society		
At Toronto	*L. G.*	418
At Ottawa	*C. E.*	425
At Hamilton	*T. H. W.*	430
At Peterborough	*D. B. M.*	431
Regina	*A. J. F.*	432
At Guelph	*J. T. L.*	435
Notes from the Dominion Observatory		
A Halo	*O. K.*	437
Notes from the Meteorological Service		
Report of the Weather in Canada, October-November	*R. F. S.*	439
Earthquake Records at Toronto and at Victoria, B. C.	*J. V.*	442
Magnetic Observations	*R. F. S.*	444
Astronomical Notes		
Possible Phase-relations between the Planets and Sun-spot Phenomena		445
The Structure of the Universe		445
Royal Meteorological Society		446
Stellar Motion and Spectral Type		446
Radio-Activity	*J. R. C.*	447
Book Reviews	*ô*	448
Notes and Queries	*C. A. C.*	449
Index to Volume V.		

Editorial communications should be addressed to C. A. Chant, University of Toronto, Toronto, Ont.

Business correspondence, remittances, etc., should be addressed to Chas. P. Sparling, Treasurer of the Society, 198 College Street, Toronto.

Communications regarding Library matters should be addressed to the Librarian.

$2.00 per annum. Single numbers, 35 cents.

Subscription to the *Journal* is included in membership fee.

Anyone wishing to purchase a Telescope may correspond with the Secretary, Toronto.

THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

OFFICERS FOR 1911

Honorary President—W. F. KING, C.M.G., LL.D., Chief Astronomer, Ottawa.
President—Professor ALFRED T. DELURY.
First Vice-President—Professor LOUIS B. STEWART.
Second Vice-President—J. S. PLASKETT, B.A.
Secretary—J. R. COLLINS. *Treasurer*—CHAS. P. SPARLING.
Recorder—LACHLAN GILCHRIST, M.A. *Librarian*—Dr. W. M. WUNDER.
Curator—ROBERT S. DUNCAN.

Council—The above Officers, and the following members: JOSEPH POPE, C.M.G., Ottawa; G. PARRY JENKINS, F.R.A.S., Hamilton; Rev. I. J. KAVANAGH, S.J., D.Sc., Montreal; Rev. Dr. MARSH, F.R.A.S., Peterboro; Dr. A. D. WATSON, Toronto; A. F. MILLER, Toronto; and Past Presidents ANDREW ELVINS, JOHN A. PATERSON, K.C., M.A.; R. F. STUPART, F.R.S.C.; Professor C. A. CHANT, W. BALFOUR MUSSON; and the presiding officer of each Centre as follows: J. S. PLASKETT, B.A.; H. B. COLLIER, PHM.B.; WM. BRUCE, J.P.; N. MACMURCHY, B.A.; Professor N. B. MCLEAN and HENRY WESTOBY, Esq.

OTTAWA CENTRE

Local President—J. S. PLASKETT, B.A.
Vice-President—R. M. STEWART, M.A.
Secretary—CARL ENGLER, B.A. *Treasurer*—C. C. SMITH, B.A.
Council—W. E. HARPER, B.A.; F. A. MCDIARMID, B.A.; J. J. MCARTHUR, D.L.S.

PETERBOROUGH CENTRE

Local President—H. B. COLLIER, PHM.B. *Vice-President*—H. O. FISKE, C.E.
Secretary-Treasurer—REV. D. B. MARSH, D.SC., F.R.A.S.
Librarian—T. A. S. HAY, C.E.
Council—D. E. EASON, B.A.SC., REV. GEO. HENDERSON, B.A., JOHN CARVETH.

HAMILTON CENTRE

Local President—WM. BRUCE, J.P.
First Vice-President—E. H. DARLING, A.M.C.S., C.E.
Second Vice-President—W. A. ROBINSON.
Secretary—T. H. WINGHAM, B.A. SC. *Treasurer*—SENECA JONES.
Council—REV. R. E. M. BRADY, D.SC.; REV. I. J. MORTON, G. PARRY JENKINS, F.R.A.S.

REGINA CENTRE

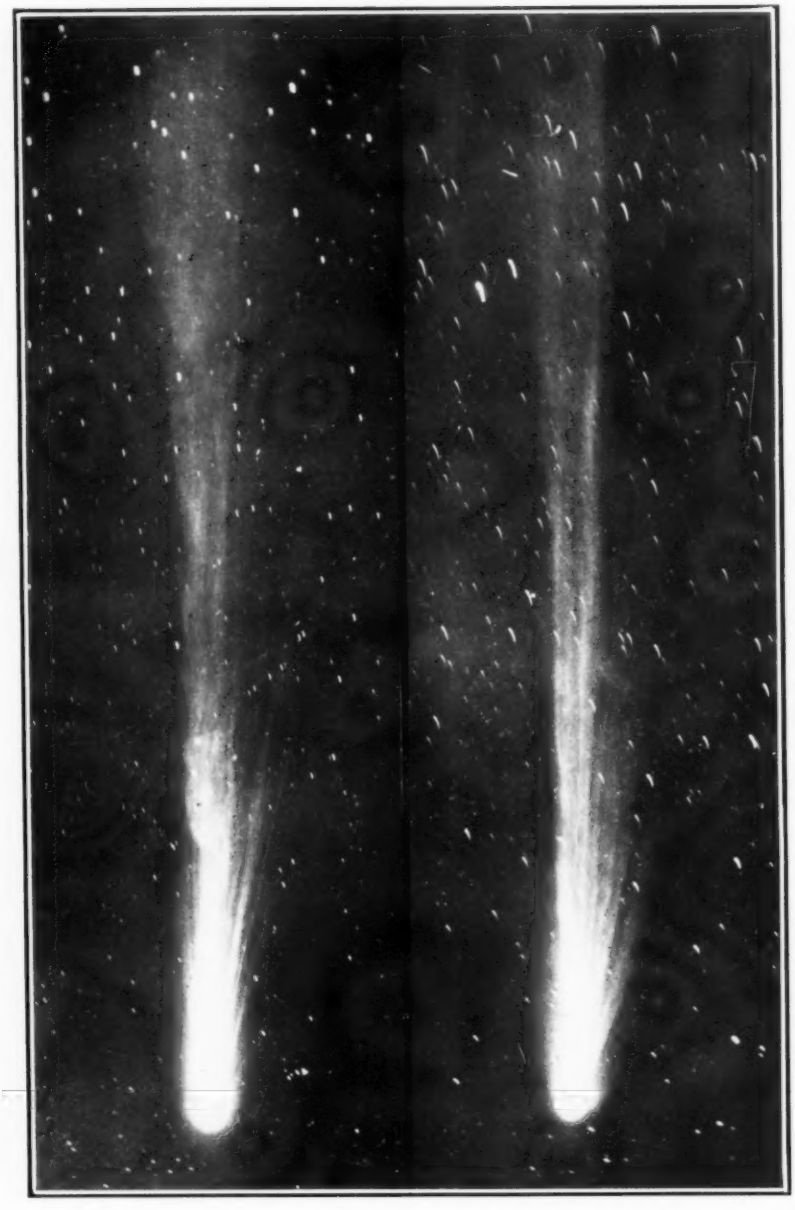
Hon. President—WM. TRANT. *Hon. Vice-President*—P. MCARA, Jr.
President—N. MACMURCHY, B.A.
First Vice-President—H. LANG. *Second Vice-President*—MRS. J. F. BRYANT.
Secretary—H. S. MCCLUNG. *Treasurer*—J. F. BRYANT.
Council—C. B. KEENLEYSIDE, J. E. DOERR, Miss E. D. CATHRO.

WINNIPEG CENTRE

President—PROFESSOR NEIL B. MACLEAN.
Vice-President—
Secretary-Treasurer—C. E. BASTIN.
Council—MRS. L. B. IRELAND, H. C. HOWARD, R. E. COLLINS, REV. FATHER J. BLAIN, S.J.; MRS. KEMP.

GUELPH CENTRE

Honorary President—COLONEL A. H. MACDONALD, K.C.
Honorary Vice-President—DR. W. F. SAVAGE.
President—HENRY WESTOBY, ESQ.
First Vice-President—PROFESSOR W. H. DAY, B.A.
Second Vice-President—DR. J. LINDSAY. *Secretary*—H. E. S. ASBURY.
Recorder—J. T. LUTON. *Treasurer*—H. J. B. LEADLAY.
Council—DR. A. H. HOBBS, REV. W. J. WILSON, W. C. MCLAREN, W. TYTLER, MRS. H. J. B. LEADLAY AND MRS. W. O. STEWART.



PHOTOGRAPHS OF COMET BROOKS, *c* 1911, taken at the Lick Observatory.

By H. D. Curtis, October 21, 1911.
Exposure 40m. Willard Lens.

By C. C. Kiess, November 4, 1911.
Exposure 1h. Dallmeyer Lens.

HEAD OF BELJAWSKY'S COMET, *g* 1911.
October 10, 1911. Exposure 19m. By H. D. Curtis, with Crossley Reflector, Lick Observatory.

HEAD OF COMET BROOKS, *c* 1911.
October 22, 1911. Exposure 54m. By H. D. Curtis, with Crossley Reflector.

THE JOURNAL

OF

THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

EDITOR

C. A. CHANT
University of Toronto, Toronto

ASSOCIATE EDITORS

W. F. KING
Chief Astronomer
Ottawa

R. F. STUPART
Director of the Meteorological
Service of Canada, Toronto

J. S. PLASKETT
Dominion Observatory
Ottawa

VOLUME V., 1911

PRINTED FOR THE SOCIETY
TORONTO: 198 COLLEGE ST.
FOREIGN AGENTS: WILLIAM WESLEY & SON,
28 ESSEX T., STRAND, LONDON.

CONTENTS OF VOLUME V.

I. JANUARY–FEBRUARY.

The Evolution of Worlds - - - - - *A. T. DeLury* 1
The Orbit of ν Orionis - - - - - *W. E. Harper* 16
Changes in Focus Produced by Plane Gratings - - *Ralph E. DeLury* 26
A Device for Guiding the Image Produced by a Coelostat Telescope - - - - - *Ralph E. DeLury* 33
Precise Measuring with Invar Wires; and the Measurement of Kootenay Base - - - - *P. A. Carson* 36
A Plea for the Reflecting Telescope - - - *G. Parry Jenkins* 59
Meetings of the Society at Toronto, 76; at Ottawa, 78; at Hamilton, 81; at Peterborough, 82. Notes from the Dominion Observatory, 84. Notes from the Meteorological Service, 85. Astronomical Notes, 90. Notes and Queries, 92.

II. MARCH–APRIL.

The Determination of Orbits - - - - - *L. B. Stewart* 97
The Spectroscopic Binary 7 Camelopardalis - - *W. E. Harper* 112
Eclipse Cycles - - - - - - *W. H. S. Monck* 117
Note on the Classification of the Chemical Type of Stars *W. Balfour Musson* 125
Meetings of the Society at Toronto, 128; at Ottawa, 131; at Peterborough, 135. Notes from the Dominion Observatory, 137. Notes from the Meteorological Service, 143. Astronomical Notes 148. Notes and Queries 154.

III. MAY–JUNE.

Terrestrial Magnetism - - - - - *Otto Klotz* 157
Calenders, Ancient and Modern - - - *Albert D. Watson* 172
Darwin's Tidal Theory - - - - - *A. J. Dempster* 185
The orbit of σ Geminorum - - - - *W. E. Harper* 200
Stereographic Projection Tables - - - - *Otto Klotz* 205
Meetings of the Society at Toronto, 216; at Ottawa, 217; at Hamilton, 221; at Guelph, 222. Notes from the Meteorological Service, 225. Astronomical Notes, 232. Book Reviews, 239. Notes and Queries, 240.

IV. JULY-AUGUST.

Some Recent Interesting Developments in Astronomy — *J. S. Plaskett* — 245
The Orbit of *h* Persei — *J. B. Cannon* — 260
Personal Errors of Bisection in Meridian Circle Work — *D. B. Nugent* — 272
Notes from the Meteorological Service, 277. Astronomical Notes, 282. Notes and Queries 286.

V. SEPTEMBER-OCTOBER

Life on Other Worlds — *R. G. Aitken* — 291
A Great Modern Telescope — *C. A. Chant* — 309
The Orbits of the Spectroscopic Components of *d* Bootis — *W. E. Harper* — 315
The Astronomical and Astrophysical Society of America — *C. A. Chant* — 327
Notes from the Dominion Observatory, 339. Notes from the Meteorological Service, 341. Astronomical Notes, 346. Notes and Queries 349.

VI. NOVEMBER-DECEMBER

Spectroscopic and Visual Binaries: An Outline of Work Done in this Field and an Indication of Its Importance — *Reynold Young* — 355
A Note on φ Persei — *J. B. Cannon* — 372
The Orbit of ω Ursæ Majoris — *T. H. Parker* — 377
Errors in the Measurement of Spectral Line Displacements — *Ralph E. DeLury* — 384
Mars: The Planet of Mystery — *C. A. Chant* — 408
Meetings of the Society at Toronto, 418; at Ottawa, 425; at Hamilton; 430 at Peterborough, 431; at Regina, 432; at Guelph, 435. Notes from the Dominion Observatory, 437. Notes from the Meteorological Service, 439. Astronomical Notes, 445. Book Reviews, 448. Notes and Queries, 449. Index to Volume V.

Errata.—To W. H. S. Monck's paper on "Eclipse Cycles."—p. 117, line 15 for "1348" read "1346." Same page, line 20 for "of" read "at." Page 122, line 4 for "portion" read "position."

THE JOURNAL
OF THE
ROYAL ASTRONOMICAL SOCIETY
OF CANADA

VOL. V. NOVEMBER DECEMBER, 1911. No. 6

SPECTROSCOPIC AND VISUAL BINARIES: AN OUTLINE OF WORK DONE IN THIS FIELD AND AN INDICATION OF ITS IMPORTANCE

BY REYNOLD YOUNG

DURING the last ten or fifteen years there has been a great number of binary orbits, both visual and spectroscopic, published in the astronomical journals. To those who are not making a special study of astronomy, the value of this work might not seem apparent. It is the purpose of this article, to outline the work which has been done in this field, and, in a brief way, to show its importance. The article purposes to have nothing original about it, but is written for the benefit of those who might sometimes ask the significance of the study of visual and spectroscopic binary stars.

Visual Binaries — In speaking of visual double stars we must distinguish between two kinds, those which are physically connected and those only optically so. In the first case the two are close together in the sky because the actual separation in miles is small, and the two suns exert a gravitational attraction on each other, causing orbital motion. In the second case the two stars may be millions of millions of miles apart but the one

lies so nearly behind the other that, as seen from the earth, they appear very close together.

Accurate measurement of the distance separating the two components and the angle that the line joining them makes with some fixed line in the sky will in time decide whether the star is a visual or an optical double. If the two stars form a true binary system, there will be a definite relation between the arc described by either component and the time. The path of each will be

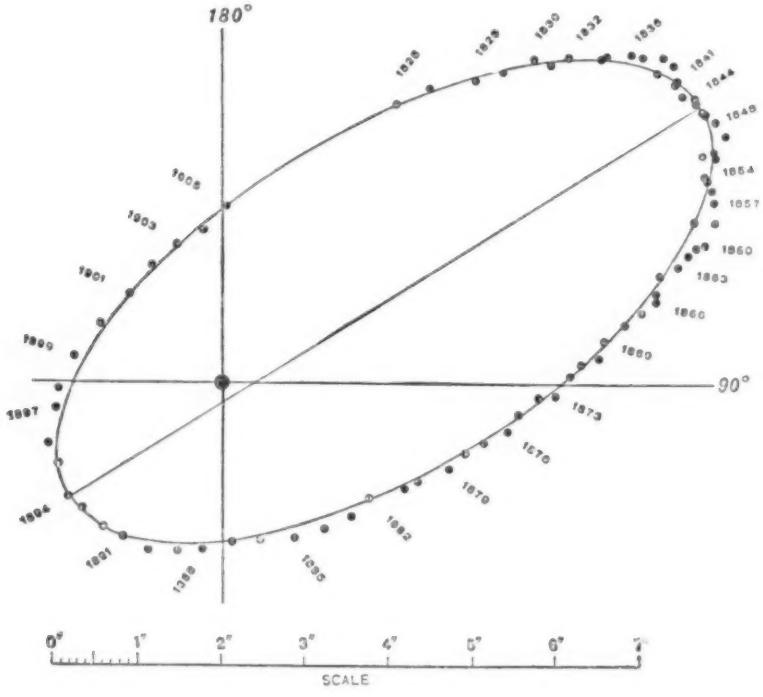


FIGURE 1.

APPARENT ORBIT OF 70 OPHIUCHI, Σ 2272

(From Burnham's *General Catalogue*, Vol. II., p. 774.)

curved in general and the two components will circle about each other. If the stars are not connected in this way they will possess different proper motions. It is known that all the stars have velocities of their own which in time displace their apparent position as seen from the earth. If then a pair of stars is only optically double the relative motion of the two will be a straight line and the two stars, after making their closest approach, will become farther and farther removed from one another. Figure 1 shows the orbit of a true binary which is well determined. Figure 2 indicates the relative motion of two stars which are only optically double.

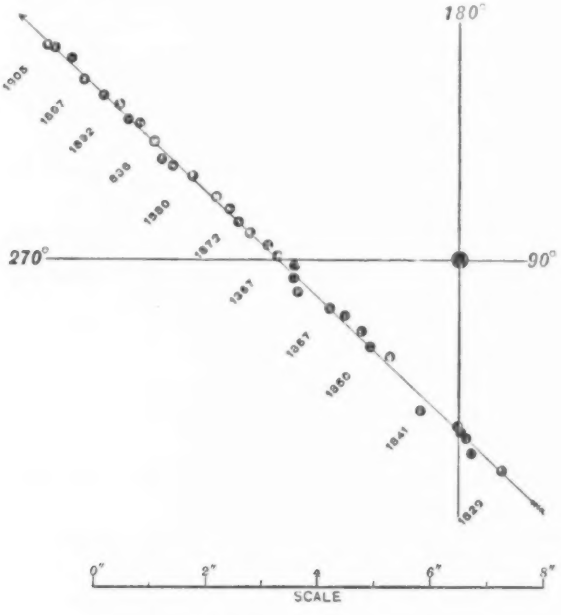


FIGURE 2.

APPARENT PATH OF 210 HERCULIS, Σ 2120.

(From Burnham's *General Catalogue*, Vol. II., p. 734).

It is difficult to assign any date to the origin of the study of double stars. The true significance of a double star was first discovered by Herschel in 1803, but the study of double stars originated long before this time. Probably the first specimen recognized as such was ζ Ursæ Majoris which Riccoli found at Bologna in 1650 to consist of a 2½ and a 4 magnitude star. A comet passing close to γ Arietis in 1665 led to the discovery of its duplex character. γ Virginis, Castor, 61 Cygni and β Cygni were noted by Bradley as being double in 1755; and in 1776 Father Christian Meyer began a systematic search for such couples. His thirty-three discoveries were but a beginning to the vast number catalogued by Herschel a few years later.

The time preceding Herschel we may call the first period in the study of double stars, for with his work a new era commenced. He undertook the accurate measurement of close doubles in the hope of finding the parallax of some of the stars. This same problem led Bradley a few years earlier to discover the aberration of light and the nutation of the earth's axis, and now it led to another most remarkable discovery. As early as 1782 Herschel had published a catalogue of double stars, but it was not until 1804 that the significance of the motion which had been observed was fully recognized. Following Herschel we have W. Struve, O. Struve, Burnham, Hussey, Aitken, Doberck, Innes and many others.

In the last few years, attempts have been made to photograph double stars, and while the method is fairly successful for stars wide apart it will hardly prove efficient for the closer pairs. The collodion emulsion with which the plates are coated has a granular structure so that the star images instead of being geometrical points have an appreciable diameter. The best images obtainable will in general be over a second of arc in diameter. It can not, therefore, be compared with the visual method, in which stars only one-tenth of a second of arc apart are plainly separated.

The profusion with which couples, so very close together, are distributed over the sky is a striking proof of the significance

of their existence. Between the years 1871-1879 Burnham discovered 1000 new double stars, of which 743 were separated by an average distance of 1·58 seconds. In order to understand how close such pairs are we may compare them to the apparent width of a ten-cent piece at a distance of one mile. Many doubles are still closer than this and the 36-inch telescope of the Lick Observatory is capable of detecting the angle subtended by a ten-cent piece at a distance of ten miles. The spectroscope has demonstrated the fact that many stars are made up of two so close together as to be beyond the reach of any telescope, and we can only say of any such star, that it has never been divided, not that it is single.

With the advance in the size and quality of optical instruments the number of double stars has increased very rapidly. General Catalogues have been prepared so that old pairs might not be listed twice and for convenience in the general study. Burnham's last catalogue, for stars within 121 degrees of the North Pole, contains more than 12000 objects. The number has increased so much that the observers in the field can not secure sufficient measures of the pairs already discovered. Some selection has to be made as to the stars which one shall include on his observing program. The chief interest centres around those pairs which will in all likelihood prove to be binary systems. It is evident that the closer together two stars are found, the greater the chance that they are physically connected. Again, two stars of the first magnitude within one second of arc from one another are much more likely to form a system that two sixth magnitude stars the same distance apart. Many observers set definite limits to what they will consider a double star. So far, these limits have been arbitrary, each observer setting limits for himself. In the *Astronomische Nachrichten*, No. 4505, June, 1911, Aitken proposes a definition of a double star for every observer to work by. The definition is given below.

"I. (Definition).

Two stars shall be considered to constitute a double star

when the apparent distance between them falls within the following limits.

1″	if the combined magnitude of the components is fainter than								11·0	
3″	"	"	"	"	"	"	"	"	9·0	B.D.
5″	"	"	"	"	"	lies between		6·0 -	9·0	"
10″	"	"	"	"	"	"	"	4·0 -	6·0	"
20″	"	"	"	"	"	"	"	2·0 -	4·0	"
40″	"	"	"	"	"	is brighter than			2·0	"

II. Pairs which exceed these limits shall be entitled to the name double star only when it has been shown, (*a*) that orbital motion exists, (*b*) that the two components have a well defined common proper motion or proper motion of the 61 Cygni type, (*c*) that the parallax is decidedly greater than the average for stars of corresponding magnitude.

III. It is respectfully requested that astronomers observe the limits given in the definition in publishing lists of new double stars. It is also strongly urged that the announcement of every new double star give it accurate identification and a correct description, (measures if possible) including the position angle, distance and relative magnitude, and also the combined magnitude from some standard photometry or from one of the Durchmusterungen."

In making this definition, the author of it states that it is not meant to discourage the measurement of wide pairs outside these limits. Its purpose is to make catalogues of discovered double stars more homogenous in the material they contain.

In this short article we cannot take time to explain the manner in which an orbit is computed from the observations, and we will confine ourselves more to the results which have been obtained. At the present time there are about fifty orbits accurately known, one hundred more are approximate, while a vast number of double stars are known to be in motion. The period of visual binary systems is in general very long, the shortest being δ Equulei with a period 5·70 years. Some doubles are known to be binaries whose period will exceed 1000 years. On account of the great length of the period, the data for the statistical

study of double stars are as yet rather meagre and some results which have been obtained will be included under the discussion of the spectroscopic binaries. There is, however, a great number of double stars known and the study of the relations existing between their brightness, separation and distance will teach us many interesting facts.

The following discussion is taken from Lick Observatory *Bulletin*, No. 176, Vol. VI.

TABLE I.

Double Stars under 5″·01 and Having One Component as Bright as 9·5 Magnitude in Burnham's General Catalogue of Double Stars

	5·5 Mag.	6·5	7·5	8·5	9·5	Total	Total Corrected for Parallax
Under 0″·51	43	88	257	699	270	1270	1048
0″·51-1″·00	51	110	260	590	236	1256	1119
1″·01-1″·50	43	70	220	502	157	992	1079
1″·51-2″·00	37	60	150	405	145	812	717
2″·01-2″·50	25	51	160	308	93	637	495
2″·51-3″·00	32	42	122	266	72	534	499
3″·01-3″·50	24	38	81	237	66	456	399
3″·51-4″·00	30	30	94	161	52	367	221
4″·01-4″·50	17	35	69	188	39	348	188
4″·51-5″·00	15	28	60	167	25	295	167
Total	317	568	1482	3442	1164	6973	5809

The second column includes all pairs for which the principal component is as bright as 6·0, the next three those for which the brighter component lies between 6·1-7·0, 7·1-8·0, 8·1-9·0; and the sixth column those in which both components are as faint as 9·1.

Examination of the above table brings out the fact that close double stars are more numerous than those wider apart. This is true of every magnitude until the separation is less than 0″·51. When we bear in mind how few telescopes can resolve stars as close as 0″·51, we are justified in assuming that the lack of double stars closer than this is due to our instrumental limitations and not to paucity in the stars themselves.

If we were to regard a visual double star as an evolved single star, the components at one time would have been very close together and would have gradually separated as time went on. It has been shown mathematically that a gaseous mass rotating, and contracting under its own gravitation may divide into two parts. When this has taken place the bodies may and will be pushed farther apart. At first the orbits will be nearly circular, but gradually will become more eccentric. Just here, mathematics raises a difficulty, for it shows that the maximum value that the eccentricity can obtain is about 0·30 and the average eccentricity of the visual binary systems is above 0·50. Whatever be the final objections to the theory from a mathematical standpoint we can see that it explains the facts set forth in the table. The assumption that all double stars were once single leads to the conclusion that at any time a great many stars are in the first stages of evolution, a smaller number, but still a large one, form close pairs and a still smaller number are widely separated. This result is here easily seen from the course of evolution as laid down by mathematics. According to these principles the high eccentricities will be rare. Many nebulæ will divide into the two components circulating in orbits without eccentricity, while only a few progress to form pairs more widely dissociated. We take pains to make this part clear, otherwise it might not seem apparent why in an infinite time there should be comparatively so few double stars. The evolution of a double star from a single star only demands that the number of stars in which the actual separation in miles is small, shall be numerous compared to those farther apart. Since for any given linear separation of two stars, the apparent angular distance diminishes, it is obvious that if we could take a star barely separable when of first magnitude and remove it till it shows as fourth magnitude it would no longer count as a double star. If now we count all stars whose angular distance apart is less than 5″·01, at 6·0 magnitude this list will include stars whose linear separation is small compared to those included in such a list at 8·0 magnitude. Hence, if our original supposition as to the evolution of a star was correct we

would expect that among the bright stars a greater proportion should show as visual doubles. That this actually is the case may be seen from the following tabulation.

TABLE II.

	6·0 Mag. or Brighter	6·1–6·5	6·6–7·0	7·1–7·5	7·6–8·0	8·1–8·5	8·6–9·0
Double stars Under 5·01	87	69	140	198	336	502	837
B.D. Stars	937	893	1741	2678	4010	10132	23343
Ratio	1:11	1:13	1:12	1:14	1:15	1:20	1:28

We will find that our assumption receives strong support from the study of spectroscopic binaries, in that about one star in four or five is a double. This large ratio comes not from the fact that spectroscopic binary stars are bright but from the fact that the spectroscope can obtain the distance of the components apart, as readily when the stars are 100 light years away as when they are 10 light years away. As the spectroscope is improved and larger telescopes gathering more light are employed, thus enabling observers to photograph fainter and fainter stars we will expect to find, not the ratio 1:15 for the 8·0 magnitude stars, but still the ratio one to four or five. The telescope when used to observe visual double stars separates many bright stars whose linear separation is so small that if the star were removed to eighth magnitude it would no longer be double. The spectroscope on the other hand operates independently of the distance.

Before leaving the visual binary systems we will refer briefly to the method of obtaining the mass. The orbit of a double star, if the distance of the star is known, affords the most accurate means for the determination of its size. The size of a star may, by certain assumptions, be determined from the distance and its brightness but the results are subject to considerable error.

If we take m_1 and m_2 for the masses of the two components, a the semi-major axis, P the period and π the parallax, we may write the following equation

$$m_1 + m_2 = \left(\frac{a}{\pi}\right)^3 \Big/ P^2$$

a and P are two of the quantities determined in an orbit, and the parallax is obtained by direct measurement. a and P are known with greater accuracy than π.

Number 24 of the *Publications* of the Astronomical Labratory at Gröningen, contains a list of the most trustworthy parallaxes that have been determined. Twenty-six of these are for stars of which binary orbits have been computed. Using this material Aitken arrives at the conclusion that the average mass is about three times that of our sun.

We should not conclude from this result that our sun is decidedly below the average in mass. At the present time only a fraction of the stars are known to be double, visually or spectroscopically, and it may be the case that those stars of relatively large mass are more subject to fission. If this were the case it would be decidedly misleading to say that our sun was smaller than the average star.

Spectroscopic Binaries — In 1842 it was pointed out by Doppler that the motion of a luminous source toward or away from the observer should affect the wave-length of the light measured. The motion of the source toward the observer may be regarded as cramping the vibrations closer together. In the diagram let S be the source and O be the observer.

If the distance from S to O be D, the time taken by the light to go from S to O will be $\frac{D}{l}$ seconds. Suppose S approaches O with a velocity of v; when the light has reached O, S will have moved to S^1, where $S\,S^1 = \frac{D}{l}\,v$. All the wave-lengths which would have occupied $S\,O$, had the source been at rest, will now be confined to the part $S^1\,O$. Consequently, if we let λ^1 be the new wave-length

$$\frac{\lambda'}{\lambda} = \frac{S'O}{SO} = \frac{D - D\frac{v}{V}}{D},$$

$$\text{or } \lambda - \lambda' = \frac{v}{V}\lambda,$$

$$i.\,e.\ \Delta\lambda = \frac{v\lambda}{V}, \text{ or } v = \frac{\Delta\lambda}{\lambda}V.$$

The velocity of light V equals 299800 kilometres per second. Considering light whose wave-length is 5000 A. U., it requires a radial velocity of sixty kilometres per second to change the wave-length one Angström unit. The above demonstration of Doppler's principle is by no means complete but it serves to give in an easy way to the formula as used in radial velocity work.

It was not until the year 1869 that the principle was applied to the determination of the radial velocity of a star. This was first accomplished by Sir William Huggins. The problem is one attended with great difficulties on account of the faintness of the source and the smallness of the displacement. The pioneer workers in this field worked by visual methods, but here especially the faintness of the source was a drawback. Vogel was the first to apply photographic methods so that the light by falling on a photographic plate for some time could plainly register the displacement. The photographic method has been improved little by little and the probable error of measurement has been decreasing until at the present time spectroscopists are attempting to measure changes in radial velocity less than one-half a kilometre per second.

Many stars, like our sun, consisting of only one body, move with constant velocity from year to year and indeed, for all we know, from century to century. When, then, a star is found whose velocity varies, we must read some interpretation into the phenomena. One can see that if we assume that the star consists of two, the one revolving around the other the result will be attained. Figure 3 gives the velocity curve of ξ Serpentis as determined by the writer in the summer of 1911. The abscissæ gives the time of observation and the ordinates give the velocity,

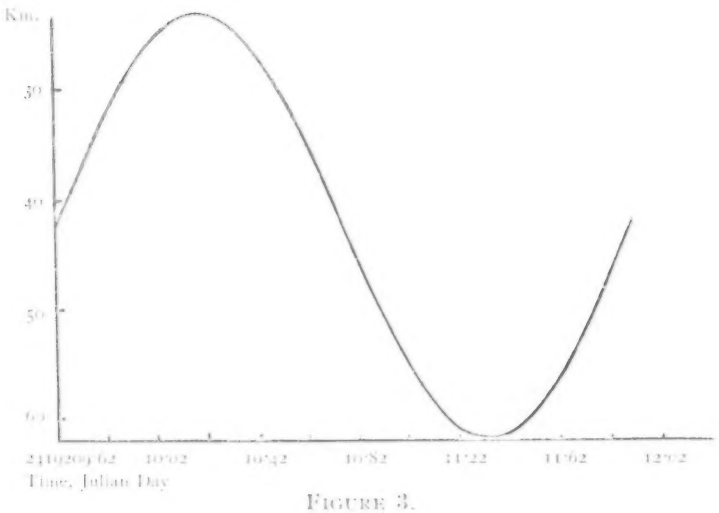


FIGURE 3.

VELOCITY CURVE OF ξ SERPENTIS, AS PLOTTED FROM OBSERVATIONS.

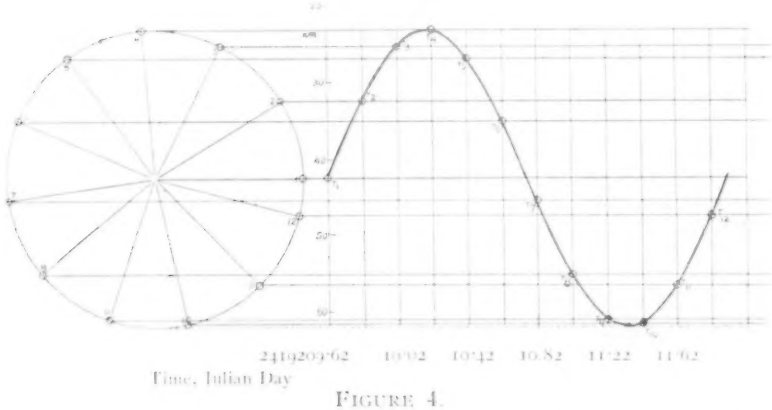


FIGURE 4.

VELOCITY CURVE OF A PARTICLE CONSIDERED AS MOVING IN A CIRCLE WITH A PERIOD OF 2·29 DAYS.

Figure 4 shows how this curve can be exactly reproduced by the projected motion of a particle moving uniformly in a circle.

The particle is supposed to travel around the circle in 2·29 days, which is the period. The radii of the circle are drawn for every fifth of a day. Suppose the particle is at 1 or T_1 when the date is the Julian Day 2419209·62 one-fifth of a day later it will have mounted to the next horizontal line and is represented by the point T_2. At the end of another fifth of a day it will be represented by the point T_3 and so on. The exact agreement between the observed curve in Figure 3 and the reproduced curve in Figure 4 leaves little doubt that the interpretation is the correct one. In the above case the orbit is nearly or exactly circular. Most binaries show a more or less elliptic form, and a graph can be constructed for them in a manner similar to the one adopted above by taking an ellipse instead of a circle and making the radius vector move around the focus so as to sweep out equal areas in equal times.

If both components of a system were equally bright, two sets of lines would be observed on the spectrograms. This is sometimes the case, but more frequently only one component is strong enough to imprint its record on the photographic plate. This does not mean that the other component is dark, but only that the difference between the two components is such that the exposure required to photograph the one is not sufficient to show the other.

In January 1905, the number of binary stars known had increased to 136 and by January 1908 to 306. At the present time it is well over 400.

The chief interest in the study of radial velocities is its bearing on questions concerning the structure of the sidereal universe. To study this we should know the radial velocity, or, in the case of a binary, the velocity of the centre of mass, of all the stars down to any given magnitude, the fainter the better. Before we can obtain the radial velocity of the centre of mass of a system its orbit must be known more or less completely. For this reason if for no other the computation of the orbits would

be of sufficient value to warrant its prosecution. The study, however, leads to other interesting problems.

On a former page it was stated that mathematics could tell us something about the probable development of a gaseous mass. It was remarked that division was possible, but that it seems improbable that the eccentricity would become very large. The problem before the astronomers is to study this question from a practical side. One sees in the sky nebulæ in varies stages of condensation and many with indications of rotation; stars in all stages of evolution, those still gaseous and single, others still gaseous but with two nuclei and so on, till we find the visual double stars whose components are far apart and condensed. Are we to infer that this has been the line of evolution? It is as if one enters a forest and finding there trees in all stages of growth from the acorn to the great oaks, infers that the one sprang from the other.

There are over seventy spectroscopic orbits determined at the present time, and about fifty visual ones. Let us endeavor to show what support these give to the theory that a double star is evolved from a single star. For a more complete discussion the reader is referred to Lick Observatory *Bulletin*, Vol. VI., No. 181, to the *Publications* of the Allegheny Observatory, Vol. I., p. 135-161, 1910, or the *Astronomische Nachrichten* Vol. CLXXXIV., p. 373-390, 1910.

SPECTROSCOPIC BINARIES — GENERAL SUMMARY

Periods	Short	0d – 5d	5d – 10d	10d +	Years	"Long"
O and *B* types	8	15	10	14	1	
Period	Short	2d·4	6d·9	73d·2	1y·0	
Eccentricity		(10) 0·04	(5) 0·10	(11) 0·34	(1) 0·0	
A types	4	10	1	12	2	
Period	Short	2d·65	9d·2	42d·2	26y·45	
Eccentricity		(5) 0·04	(1) 0·50	(8) 0·55	(1) 0·59	
F types	0	6	2	4	3	1
Period		3d·1	5d·6	145d·1	11y·1	Long
Eccentricity		(4) 0·05	(1) 0·01	(3) 0·15	(3) 0·44	
G to *M* types	0	0	0	3	9	13
Period				104d·8	24y·3	Long
Eccentricity				(2) 0·06	(8) 0·38	
Total	12	31	13	33	15	14
Mean Period	Short	2d·59	6d·90	73d·5	20y·5	Long
Mean Eccentricity		(19) 0·04	(7) 0·14	(24) 0·36	(13) 0·38	

The above table is taken from Campbell's Second Catalogue of binary stars and conveys a great deal of information regarding spectroscopic orbits. The construction of the table requires a little explanation. The rows divide the orbits into 6 classes according to their length of period, as indicated in the first line. In addition each type of star is set off by itself as indicated in the first row. When the period is marked "short" it is unknown, and the same remark applies to the word "long" in the last column.

The remarkable relation between the length of period and the eccentricity is here very apparent and the progression is still more strengthened if we add the fact that twenty-five visual systems whose period is 32·8 years have an average eccentricity of 0·48, and twenty-five whose period is 108 years have an average eccentricity of 0·51. It is not here intended to enter into a discussion of the meaning to be ascribed to the different types of stars further than to say that the line of evolution is from the *O* and *B* to the *G* and *M*. The density of the *O-B* types is in general very small, the stars being of very large size. As we pass to the later types the stars are more condensed. In this connection it might

be well to insist on the notion that we do not imply that the *M* types are older in years than the *B*s. When we consider that time is infinite and that matter may have existed for ever, such an interpretation would have little meaning. What is meant when we say that an *M* type star is older than a *B* is, that it has reached a stage which the *B* has not yet been through and which it may at some time reach. This does not imply that the *B* type star is younger than the other. It may develop more slowly. With this interpretation of the meaning of the different types of stars in mind we can summarize the results given in the table in the following manner. The progress of the stars is from the *B* to the *M* type star; from short periods, and, therefore, small semi-major axes, to pairs which are more and more widely separated; from low eccentricities to high eccentricities. The fact that very few stars are visual doubles with high eccentricities is accounted for if we assume that the mathematical statement that high eccentricities cannot exist, means that the probability of their existing is very small. It should not be contended that all double stars evolve from one nebula which divides while rotating and contracting. Independent condensations might form at different parts and give rise to stars, but the evidence is greatly in favor of the hypothesis that the double star has evolved as indicated. The parent nebula divides into two gaseous masses whose magnitudes are nearly equal. As the rotation continues the eccentricity increases and the tidal action pushes the two parts asunder. The two stars now formed begin to contract about their own centres. In the majority of cases the eccentricity remains small and the separation takes place very slowly, but in rare cases, depending probably on the initial conditions, the bodies may separate rapidly and the eccentricity be large.

It was mentioned that when the nebula divides it is believed that the masses of the two parts are nearly equal. A spectroscopic binary orbit enables one to calculate the relative mass when both components are visible. Spectra of this class are more frequently met in the *B* type stars than in any other, and

it has been found that the masses of the two components are nearly equal and that they are of the same type.

Before all the questions which enter into the life history of a star can be answered definitely it will be necessary to secure examples of many more orbits. The need of more data may be illustrated from the table giving the general summary for spectroscopic binary stars. Examining the *B* and the *A* types it will be observed that the eccentricities in the *A* types increase more rapidly with the lengthening period than do the *B*'s. We cannot attach much weight to this relation because the number of stars on which it rests is very small. If the same thing held true when we had tabulated hundreds of stars belonging to each class we would have strong confirmation that the relation was real.

In the study of the radial velocity of the stars the great problem concerns the structure of the universe, the number of the stars, their division into classes, the relative distance of these classes and their velocities. In the study of the visual and spectroscopic binaries we are concerned with the individual member. By studying the whole as they exist at any time we endeavor to trace what has been and what will be the life of each.

A NOTE ON ϕ PERSEI

By J. B. Cannon

IN a paper, "Uber das Spectrum und die Radialgeswindigkeit von ϕ Persei," *A. N.*, No 4442, Mr. Ludendorff publishes a solution of this system. His main curve goes up at its maximum to about + 53 and down at its minimum to about − 33. In the work done here on this star, (this JOURNAL, Vol. IV., No. 3), the maximum found was + 42 and the minimum − 18. This seemed so great a difference that a few plates were taken this year the measures of which might be some check on the work of last year. Seven plates were taken with this end in view and their measures are given below together with the date, phase and residual from the curve formerly derived.

Plate Number	Julian Day	Velocity	Phase	Residual O-C
4485	2419260·86	5·0	84·94	+ 13·5
4490	263·77	− 22·0	87·85	4·0
4494	266·88	− 16·4	90·96	− 0·9
4549	293·76	+ 33·4	117·84	+ 4·4
4550	293·76	+ 29·8	117·84	+ 0·8
4582	300·79	+ 44·4	124·87	+ 1·9
4583	300·79	+ 41·7	124·87	− 0·8

As will be seen from the residuals given above, these measures fit in with the curve given in the former paper very well indeed. The first measure gives a rather large residual but it was a poor plate. The others are very satisfactory.

In order to get an idea of the reliability of these measures at maximum and minimum, all the plates at these two points were grouped and the probable error of an average plate found in each case. At the maximum, plates were taken from phases 117 to 132, and at the minimum from 76 to 90. The probable errors found were respectively ± 2·0 and ± 4·6, the latter being much

greater on account of the character of the spectrum at this point. These compare very favorably with the probable error of an average plate over the whole orbit, that being ± 4·1. It will be noted that at the minimum region there were two plates omitted in the determination of the probable error. These were Nos. 2377 and 2616, which had abnormal residuals of opposite sign, being + 20 and − 22 respectively. They would of course, if included, raise the probable error considerably but could hardly be considered average plates. As far as the position of the minimum is concerned, and it is this position which we are discussing here particularly, the two plates, being of opposite sign, could not effect it in the least.

MEASURES OF φ PERSEI AT MAXIMUM

Plate Number	Phase	Velocity	Wt.	Residual	Plate Number	Phase	Velocity	Wt.	Residuals
2012	121·63	+ 30·4	5	− 0·6	3055	125·08	+ 44·9	6	+ 2·3
2505	120·08	+ 32·6	3	3·0	4549	117·84	+ 33·4	8	+ 4·4
2753	120·87	+ 39·8	6	+ 3·8	4550	117·84	+ 29·8	7	+ 0·8
2762	122·81	+ 30·4	8	3·0	4582	124·87	+ 44·4	7	+ 1·9
2764	125·83	+ 50·3	4	+ 7·3	4583	124·87	+ 41·7	7	− 0·8
3054	125·08	+ 45·6	6	+ 3·0					

MEASURES OF φ PERSEI AT MINIMUM

Plate Number	Phase	Velocity	Wt.	Residual	Plate Number	Phase	Velocity	Wt.	Residual
2022	77·85	− 18·9	4	− 1·3	2044	80·24	− 11·8	2	+ 6·0
2032	78·93	− 22·7	4	− 4·7	2045	80·24	− 18·0	4	+ 0·4
2043	80·89	− 16·9	5	+ 2·0	2052	83·28	− 8·6	5	+ 10·6
2050	84·85	− 16·7	5	+ 1·9	2053	83·28	− 15·4	7	+ 3·2
2051	84.85	− 23·5	5	4·6	2054	83·28	− 17·4	6	+ 1·2
2061	85·93	− 13·0	5	+ 5·6	2062	86·10	− 6·3	7	+ 11·9
2064	90·82	− 20·7	7	− 14·3	2063	86·10	− 5·5	3	+ 12·7
2068	91·77	− 12·8	7	+ 1·8	4485	84·94	− 5·0	4	+ 13·5
2035	76·24	7·6	3	+ 9·4	4490	87·85	− 22·0	8	4·0
2036	76·24	− 18·5	4	− 1·5	4494	90·90	− 16·4	8	− 0·9

There now follow the measures on which the former paper was based. These were not published at that time, and it was thought that they might prove of some value in connection with any work being done on this star at a later date.

Summary of Measures of ϕ Persei

Plate Number	Julian Day	Velocity	Wts.	Phase	Residual O–C
1996	2418278·60	+ 11·7	6	114·68	− 10·0
2012	285·55	+ 36·4	5	121·63	− 0·6
2028	292·55	+ 38·9	8	2·13	− 4·0
2042	294·58	+ 40·4	8	4·16	± 0·0
2053	297·62	+ 36·9	6	7·20	± 3·9
2088	313·48	+ 2·6	7	23·06	+ 2·6
2130	322·50	− 5·2	7	32·08	− 1·8
2167	325·57	+ 5·7	8	35·15	+ 8·7
2168	325·57	+ 7·4	6	35·15	+ 10·4
2221	341·45	+ 3·8	8	51·03	+ 6·0
2240	346·45	+ 2·1	7	56·03	+ 7·1
2377	381·55	+ 5·3	5	91·13	+ 20·3
2406	388·54	− 17·4	4	98·12	− 10·0
2426	389·56	− 12·6	6	99·14	− 7·0
2505	416·50	+ 32·6	3	126·08	− 3·0
2515	420·88	+ 40·4	4	3·96	± 0·0
2516	420·88	+ 38·1	5	3·96	− 2·3
2531	425·70	+ 41·9	3	8·84	+ 9·5
2534	425·86	+ 42·8	3	8·94	+ 10·4
2550	458·84	− 6·9	6	41·92	− 5·3
2561	465·83	− 3·7	2	48·91	− 1·7
2570	472·83	− 11·8	9	55·91	− 6·8
2603	486·83	− 12·5	4	69·91	− 1·3
2610	492·81	− 38·7	5	75·89	− 21·7
2622	494·77	− 18·9	4	77·85	− 1·3
2632	495·85	− 22·7	4	78·93	− 4·7
2643	497·81	− 16·9	5	80·89	+ 2·0
2650	501·77	− 16·7	5	84·85	+ 1·9
2651	501·77	− 23·5	5	84·85	− 4·9
2661	502·85	− 13·0	5	85·93	+ 5·6
2664	507·74	− 20·7	7	90·82	− 14·3
2668	508·69	− 12·8	7	91·77	+ 1·8
2673	514·78	− 7·8	9	97·86	− 0·0
2678	515·72	− 12·3	8	98·80	− 6·5
2692	518·80	− 14·9	8	101·88	− 13·9
2707	521·80	+ 5·6	7	104·88	+ 1·2
2713	522·80	+ 4·3	8	105·88	+ 1·7
2714	522·80	+ 1·7	9	105·88	− 4·3
2727	525·82	+ 14·6	7	108·90	+ 2·6
2728	525·82	+ 15·6	6	108·90	+ 3·6
2732	528·83	+ 13·5	6	111·91	− 4·0
2733	528·83	+ 17·6	7	111·91	− 0·1
2742	529·83	+ 22·2	7	112·91	+ 3·2
2749	531·73	+ 22·0	8	114·81	− 0·0
2753	537·79	+ 30·8	6	120·87	+ 3·8
2762	539·73	+ 36·4	8	122·81	− 3·0
2764	542·75	+ 50·3	4	125·83	+ 7·3
2769	545·72	+ 45·3	5	2·30	+ 2·3
2785	594·62	− 0·2	3	21·20	− 2·4
2786	594·62	+ 1·1	6	21·20	− 1·1
2787	594·62	− 2·3	5	21·20	− 4·5
2797	597·82	− 12·6	5	24·40	− 11·2

SUMMARY OF MEASURES OF φ PERSEI—(*Continued*)

Plate Number	Julian Day	Velocity	Wt.	Phase	Residual O-C
2803	2418570·73	- 13·2	6	27·31	- 10·2
2804	570·73	- 8·5	8	27·31	- 5·5
2812	571·63	- 2·8	5	28·21	+ 0·2
2813	571·63	- 4·9	7	28·21	- 1·9
2820	574·74	+ 0·2	7	31·32	+ 3·6
2823	577 67	+ 0·0	8	34·25	+ 3·4
2824	577·67	+ 5·6	7	34·25	+ 9·0
2827	578·78	- 1·4	6	35·30	+ 1·6
2828	578·78	+ 1·1	5	35·30	+ 4·1
2833	580·62	+ 0·6	7	37·20	+ 3·4
2834	580 62	- 0·2	6	37·20	+ 2·4
2840	584·69	- 0·2	6	41·27	+ 1·2
2841	584·69	+ 7·9	6	41·27	+ 9·3
2853	586·56	- 7·5	5	43·14	- 6·1
2854	586·56	- 0·5	6	43 14	+ 0·8
2870	588·66	- 4·8	6	45·24	- 3·6
2871	588·66	+ 4·4	6	45·24	+ 5·6
2880	592 78	- 0·6	9	49·30	+ 1·4
2881	592·78	- 3·5	7	49·30	- 1·5
2885	595·79	- 5·3	9	52·37	1·9
2886	595·79	- 10·7	8	52·37	- 7·3
2893	599·77	- 6·0	9	56·35	1·0
2894	599·77	- 7·8	6	56·35	- 2·8
2903	600·73	- 4·0	7	57·31	+ 1·6
2904	600·73	- 6·1	7	57·31	- 0·5
2911	607·57	- 9 9	5	64·15	+ 0·5
2912	607·57	- 8·5	5	64·15	+ 1·9
2914	608·70	- 13·7	7	65·28	2·7
2915	608·70	- 11·1	7	65·28	- 0·1
2925	609·81	- 11·0	7	66·39	+ 0·6
2926	609·81	- 8·3	3	66·39	+ 3·3
2930	615·57	- 7·8	4	72·15	+ 7·2
2931	615·57	- 11·3	5	72·15	+ 3·7
2935	619·66	- 7·6	3	76·24	+ 9·4
2936	619·66	- 18·5	4	76·24	- 1·5
2944	623·66	- 11·8	2	80·24	+ 6·6
2945	623·66	- 18·0	4	80·24	+ 0·4
2952	626·70	- 8·6	5	83·28	+ 10·6
2953	626·70	- 15·4	7	83·28	+ 3·2
2954	626·70	- 17·4	6	83·28	+ 1·2
2962	629·52	- 6·3	7	86·10	+ 11·9
2963	629·52	- 5·5	3	86·10	+ 12·9
2973	637·55	- 9·4	5	94·13	+ 2·7
2974	637·55	- 9·4	7	94·13	+ 2·4
2976	637·55	- 14·0	7	94·13	- 2·2
2989	642·50	- 11·6	9	99·08	- 5·6
2990	642·50	- 12·7	9	99·08	- 6·7
3020	651·60	+ 15·6	10	108·18	+ 5·2
3032	657·61	+ 29·8	5	114·19	+ 8·2
3033	657·61	+ 21·9	5	114·19	- 0·2
3034	657·61	+ 16·2	7	114·19	- 5·4
3051	659·79	+ 24·0	4	116·37	- 1·6

SUMMARY OF MEASURES OF φ PERSEI—(*Continued*)

Plate Number	Julian Day	Velocity	Wt.	Phase	Residual O-C
3052	2418059·79	+ 32·8	4	116·37	+ 7·2
3054	668·50	+ 45·6	6	125·08	+ 3·0
3055	668·50	+ 44·9	6	125·08	+ 2·3
3062	670·56	+ 43·4	7	0·64	− 0·6
3078	672·52	+ 38·3	5	2·60	− 4·0
3079	672·52	+ 33·9	7	2·60	− 8·4
3082	676·50	+ 44·4	7	6·58	+ 12·0
3083	676·50	+ 41·2	6	6·58	+ 8·8
3088	682·51	+ 31·5	4	12·59	+ 11·5
3089	682·51	+ 5·9	4	12·59	− 14·1
3095	684·48	+ 5·8	3	14·56	8·6
3096	684·48	− 0·6	3	14·56	− 15·0
3097	684·48	+ 14·8	4	14·56	− 0·4
3109	686·72	+ 11·9	5	16·80	+ 1·9
3110	686·72	+ 10·6	5	16·80	+ 0·6
3124	687·76	+ 5·4	5	17·84	− 2·0
3152	700·53	− 2·6	7	30·61	+ 0·8
3153	700·53	− 0·7	7	30·61	+ 2·7

DOMINION OBSERVATORY
OTTAWA, CANADA

THE ORBIT OF ω URSÆ MAJORIS

By T. H. Parker

THE star ω Ursæ Majoris, $\alpha = 10^h\ 48^m$, $\delta = +43^\circ\ 43'$, phot. mag. 4·8, was announced as a spectroscopic binary by Vogel in 1903.* It was included in a list of 528 stars whose spectra were investigated by Vogel and Wilsing at Potsdam. Vogel states that on one plate he found an indication of the doubling of the K line, and the *Mg*. line λ 4481 doubled on one or two others.

It was first observed here in February 1908, and since then sixty-nine spectrograms have been obtained—fifteen with the old, and the remainder with the new single-prism spectrograph. This star is of the *A* type, according to the Harvard classification, the principal lines being measured being the *Mg*. λ 4481, the hydrogen series and K. Only three of the plates obtained here show definite double lines. This is probably due to the faintness of the secondary component, whose mass, as will be seen later, is only about one sixth that of the primary, as well as to insufficient dispersion in separating the two spectra. The length of exposure required for a star of this magnitude forbade the use of the three-prism instrument. On this account also "Seed 27" plates were used for the majority of the spectrograms. Six were taken however on "Seed 23," and the finer grain gave a much better spectrum. The average length of exposure required for these was 90 minutes. The blending of the lines of the two spectra made the measurement of the plates rather unsatisfactory. In one plate in which the lines were separated those which showed doubling were the *Mg*. line λ 4481 and the two iron lines λ 4325 and λ 4308. In another the lines λ 4308 and λ 4101 (*Hδ*) were found to be doubled, with faint

* *Astronomische Nachrichten*, Vol. CLXIII., p. 145, 1903.

indications also of a secondary spectrum in the iron lines λ 4549, λ 4325 and λ 4260. In the third plate only λ 4308 was measurable. No trace of a doubling of the K line was found on any of our plates.

The lines measured were as follows:

Elements	Wave-Length	No. of Times Measured
Hβ	4861·527	12
Fe	4549·760	46
Mg	4481·400	69
Hγ	4340·034	58
Fe	4325·939	5
Fe	4233·328	7
Si	4128·211	9
Hδ	4101·890	33
Ca (K)	3933·825	39

The hydrogen lines with the exception of *Hγ* are broad and diffuse. The *Mg*. λ 4481 is the best line in the spectrum and was measured on every plate as will be seen in the table above. Metallic lines other than *Mg*. λ 4481, *Fe* λ 4549 and K do not occur frequently. As different lines on the same plate in many cases gave widely differing velocities the determination of the period offered some difficulty. Several such plates were remeasured or checked by other observers, and the resulting means taken. These measures were usually in fair agreement. From the consideration of the velocities of the *Mg*. line alone the period was found to be between fifteen and sixteen days. Several trials using the velocities of whole plates gave 15·84 days as the most satisfactory period.

Following is a table of observations with data of each plate:

Plate	Julian Date	Phase from Final T	Velocity	No. of Lines	Weight	O - C
1340	2417993·801	2·701	12·1	6	5	+ 5·1
1386	8010·713	3·772	− 24·1	4	6	+ 0·9
1489	047·695	9·074	− 43·5	4	4	− 12·1
1499	049·695	10·079	− 6·0	1	2	+ 18·3
1537	080·661	10·360	− 19·2	1	2	+ 8·0
1579	098·656	12·515	27·5	6	3	− 13·2
1637	119·621	1·799	− 22·3	2	2	− 14·3
2021	285·941	9·720	− 38·3	2	2	− 8·8
2037	292·938	0·877	− 2·7	4	4	4·2
2063	297·934	5·873	− 29·3	6	6	+ 3·4
2099	313·897	5·999	− 26·9	5	5	+ 5·9
2232	341·807	2·229	− 12·7	6	7	6·0
2259	346·795	7·214	− 22·9	2	2	+ 10·9
2299	360·757	5·130	− 26·0	6	4	+ 5·0
2321	369·750	14·329	+ 0·7	5	4	− 0·4
2340	374·741	3·479	− 31·7		2	− 8·3
2354	378·681	7·420	− 34·5	4	4	0·8
2369	370·694	8·433	30·4	4	6	+ 2·4
2411	388·699	1·598	13·8	2	4	− 8·2
2431	389·719	2·618	− 6·4	3	3	+ 9·6
2447	397·671	10·570	− 17·5	2	5	+ 8·7
2466	398·786	11·685	− 21·5	2	4	− 1·0
2480	405·625	2·679	− 20·7	5	6	− 3·6
2494	413·633	10·692	− 32·4	2	2	6·8
2500	416·510	13 569	+ 2·3	2	4	+ 7·8
2508	420·443	1·662	− 6·4	3	3	0·6
2520	425·685	4·901	− 34·1	4	6	3·0
2525	425·621	6·840	− 48·5	2	2	− 14·3
2535	430·577	11·796	0·9	2	3	+ 12·8
2549	451·640	1·179	+ 0·2	3	6	+ 1·0
2551	453·688	3 227	5·1	2	2	+ 16·0
2552	418458·692	8·231	− 37·9	3	1	5·8
2557	460·598	10·137	− 39·3	3	2	11·3
2571	473·667	7·366	− 41·7	2	1	8·0
2583	482·637	0·496	0·0	2	5	− 4·9
2878	588·906	11·725	− 20·0	3	4	+ 0·1
2959	620·899	2·198	− 12·5	6	6	+ 0·3
3112	686·822	14·601	0·0	3	6	3·3
3144	697·833	9·772	28·2	6	7	+ 1·2
3161	703·715	15·654	+ 13·0	4	6	+ 5·5
3198	721·687	1·946	18·2	2	3	8·0
3205	724·702	4·961	− 34·2	4	6	− 3·8
3212	726·723	6·982	− 42·0	2	2	− 8·3
3248	731·687	11·946	26·3	4	4	8·0
3256	733·688	13·947	− 9·4		2	− 7·2
3282	734·807	15·066	− 4·5	5	3	− 10·6
3321	742·636	7·055	− 25·7	5	4	+ 8·3
3340	749.566	13·985	− 5·3	4	5	3·3
3353	747·697	12·161	12·5	4	5	+ 4·7
3357	754·674	3·253	25·9	3	3	− 4·2
3364	759·680	8·259	27·0	3	5	+ 4·9
3375	768·639	1·379	+ 8·4	5	4	+ 11·2
3377	770·666	3·409	− 20·0	5	6	+ 2·9
3388	774·817	7·556	33·1	5	5	+ 0·2
3391	775·611	8·350	30·8	3	4	7·0

Plate	Julian Date	Phase from Final T	Velocity	No. of Lines	Weigh	O - C
3395	2418770·646	9·385	29·6	6	5	− 0·9
3397	782·666	15·405	+ 9·9	6	6	+ 2·5
3406	787·625	4·524	− 29·3	5	6	0·2
3407	789·627	6·526	− 31·5	6	4	+ 2·0
3416	790·594	7·493	− 40·8	5	6	− 7·1
3422	797·549	14·448	+ 2·8 * − 145·13	5	6	+ 0·7
3441	803·639	4·698	− 32·7	3	5	2·9
3454	811·653	12·712	− 13·0	5	4	0·0
3866	6018·905	14·104	+ 5·2	6	2	+ 6·0
3893	027·880	7·179	+ 114·6 * − 34·03	3	4	− 0·2
4094	106·826	6.925	+ 83·7 * − 36·83	4	3	3·1
4182	137·786	6·205	− 31·1	5	5	+ 2·0
4231	148·700	1·279	− 8·1	6	4	0·1
4267	153·771	6·350	− 32·3	5	3	+ 0·9

* Double spectrum.

The phases are computed from the final value of T, and the residuals are scaled from the corrected curve. The plates were grouped into seventeen normal places, according to phase, and each weighted as in table below.

NORMAL PLACES 1ST SOLUTION

No.	Julian Date	Phase	Velocity	Weight	Residuals O-C
1	2418303·130	1·210	+ 1·50	1·0	+ 4·53
2	742·924*	1·733	1·75	2·0	4·49
3	745·191	2·793	+ 11·44	1·0	+ 1·68
4	419·903	4·224	2·87	2·0	3·96
5	448·513	5·567	13·22	2·5	+ 1·86
6	754·423	6·105	21·02	1·0	1·74
7	020·966	6·155	19·24	1·5	+ 1·30
8	770·127	7·831	32·05	2·0	2·19
9	349·629	8·623	29·49	2·0	+ 2·68
10	771·435	10·293	34·45	2·0	0·45
11	391·880	10·847	33·95	1·5	− 0·13
12	746·138	12·140	30·70	2·0	+ 1·52
13	058·684	12·600	35·40	·5	− 4·17
14	391·700	13·459	27·95	1·0	+ 0·68
15	070.030	15·040	18·90	·5	+ 2·82
16	476·591	14·834	16·97	1·0	+ 4·75
17	762·440	15·340	16·90	1·5	+ 2·23

A velocity curve was drawn through the normal places by the graphical method of Dr. King, giving the following preliminary elements :

$P = 15{\cdot}84$ days,
$e = {\cdot}30$,
$\omega = 10°$,
$K = 22$ km.,
$\gamma = -18{\cdot}50$ km.,
$T = 2417991{\cdot}168$ J. D.

A least squares solution with these elements gave the following corrections:

$\delta P = +\ 00008$ days,
$\delta \gamma = +\ 0{\cdot}17$ km.,
$\delta K = -\ 2{\cdot}03$ km.,
$\delta e = -\ {\cdot}060$,
$\delta \omega = +\ 4° 13$,
$\delta T = +\ 0{\cdot}018$ days.

The value of Σpvv was reduced from 193 to 137. On substitution in the observation equations it was found that the computed and ephemeris residuals did not agree closely. A second solution was accordingly made. The velocities of six additional plates were included which had been obtained after the first solution was made. The number of normal places was reduced to ten and the period taken as fixed at 15·8401 days. The normal places for the second solution follow. In the last column will be found the residuals from the final curve.

	Julian Date	Phase	Velocity	Weight	Residual
1	2418682·660	1·541	0·44	3	1·0
2	743·191	2·791	+ 10·45	1	+ 3·9
3	568·528	4·280	− 2·70	3	1·8
4	379·090	5·364	− 14·59	3	0·8
5	450·809	6·616	− 24·09	2	0·2
6	537·746	8·269	− 30·62	4	+ 0·4
7	740·258	10·118	− 34·32	4·5	0·5
8	574·889	12·012	− 32·45	3	0·6
9	343·848	13·460	− 26·91	1	+ 0·5
10	536·191	15·092	− 17·25	3	+ 1·1

The solution of these gave as further corrections:

$$\delta\gamma = + \cdot 51 \text{ km.},$$
$$\delta K' = + \cdot 39 \text{ km.},$$
$$\delta e = + \cdot 024,$$
$$\delta\omega = - 2^\circ \cdot 177,$$
$$\delta T = - \cdot 085 \text{ days.}$$

The definitive elements of the orbit now were :

$$P = 15 \cdot 8401 \text{ days},$$
$$e = \cdot 264,$$
$$\omega = 11^\circ \cdot 95,$$
$$K' = 20 \cdot 64 \text{ km.},$$
$$\gamma = - 18 \cdot 45,$$
$$T = 2417991 \cdot 101 \text{ J. D.}.$$

The value of Σbvv was reduced from 43 to 33, and the agreement between the computed and ephemeris residuals was now satisfactory, the greatest difference being ·08 km. The table below gives a summary of the values of the elements after each solution.

Element	Preliminary Values	First Corrected Values	Final Values
P	15·84 days	15·8401	15·8401 days
e	·30	·24	·264 ± ·024
ω	10°	14°·13	11°·95 ± 5°·57
K'	22 km.	20·25	20·64 ± 0·40
γ	18·50 km.	− 18·96	18·45 ± 0·32
T	2417991·168 J. D.	. . . . 991·186 J. D.	. . . . 991·101 J. D. ± ·208
$a \sin i$			4,336,000 km.

In the column of final values is also given the probable error for each element. The probable error of a normal place of unit weight was ± 1·7 km., and that of a plate of average weight was computed from the residuals scaled from the final curve and found to be ± 4·1 km.

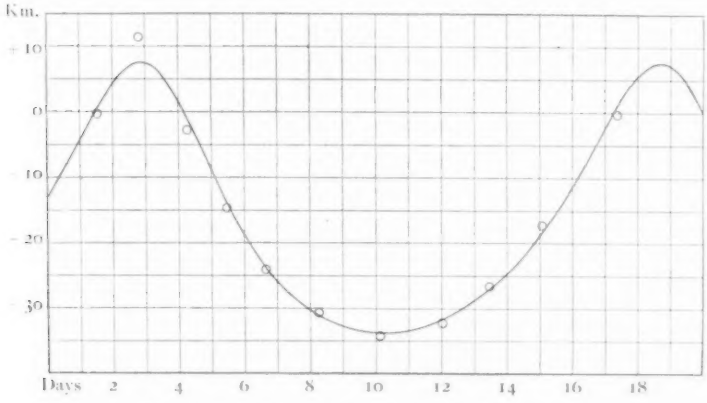
Although there are only three measures of the secondary component an approximation to the value of K' was arrived at by substitution in the equation :

$$\frac{dz}{dt} = \gamma + K' \left(\cos u + e \cos \omega \right)$$

giving the velocity at any point in the orbit. The values of c, ω and γ being known, that of u was determined in the usual way from the mean anomalies at the observed velocities. Successive trials of the value of K' in the above equation gave 120 km. as the most satisfactory. Hence a comparison of the masses of the system may be had from the relation :

$$M_1 : M_2 = K'_2 : K'_1 = 120 : 20{\cdot}6 = 5{\cdot}8 : 1.$$

It is interesting to note that if further measures of the secondary substantiate this value of K' this proportion of the



VELOCITY CURVE OF ω URSÆ MAJORIS

masses is one of the highest yet obtained. It is probably due to the resulting faintness of the companion that more plates showing the double spectrum were not obtained.

In conclusion I wish to acknowledge with thanks the kindly interest shown by the Director throughout this work.

DOMINION OBSERVATORY,
OTTAWA, CANADA.
December, 1911

ERRORS IN THE MEASUREMENT OF SPECTRAL LINE DISPLACEMENTS

By Ralph E. DeLury

THE presence of systematic errors of a personal nature in the measurements of the positions of spectrum lines has often been suspected, yet little attempt has been made to determine their character and magnitude. In the present paper a method for investigating and eliminating these errors is described along with some measurements made in connection with the problem of the solar rotation, after first briefly mentioning some of the more important questions likely to be affected by such errors.

Systematic personal errors are suspected to occur in the measurements of the following investigations:

(*a*) *The determination of wave-lengths.* The greater part of this work involves repeated "settings" on the lines whose wave-lengths are sought and on other lines called "standards" whose wave-lengths are known. These "settings" consist in turnings of a micrometer-screw carrying the measuring microscope or the photograph of the spectrum, until the line or lines of the microscope are placed as closely as the measurer can see, over or symmetrically about the centres, centres of intensity or some other selected part of the spectrum lines and recording the corresponding scale-readings. It is obvious that if one observer uses the centre of the line for his settings and another uses the centres of intensity, systematic errors will occur, since for some lines the two "centres" coincide, while on others they do not. Again, even if two persons strive to set on the same part of the line such things as unsymmetrical shading of the line, the nearness of other lines, etc., may affect them differently and result in different settings with consequent errors in the determination of the wave-length. Such errors are so small, when the spectrum

is on a large scale, that for ordinary purposes the measurements are sufficiently accurate. In the determination of standard wave-lengths, however, an effort should be made to eliminate even these errors. It is generally assumed that the mean of the measurements of several measurers is well within the limits of the accidental errors. This is not necessarily the case, however, for disturbing influences such as those mentioned above may operate on the measurements systematically in the same way for the different persons. There is apparently some evidence of this in the determination by interferometer methods of the "Secondary Standards of Wave-length, International System, in the Arc Spectrum of Iron,"* by Fabry and Buisson, Eversheim and Pfund, as the following quotation from H. Kayser's paper on "Standards of Third Order of Wave-lengths on the International System," † would seem to show: "I have employed as standards the arithmetical means of the measurements of Fabry and Buisson, Eversheim and Pfund. The portions of spectrum measured were always between three or four successive standards, so that each line is referred to as many neighboring standard lines as possible. It turned out that measurements of the same sharp line on different plates yielded differences of not more than from 0·001 to 0·002Å when the same standards were employed; but if different standards were employed, differences as great as about 0·006 occurred. This proves that some of the standards contain errors of from 0·004 to 0·005Å, and that measurements of the best plates in the second order give a greater degree of accuracy than that of the secondary standards." I cannot say that I am wholly convinced by the argument. It seems to me quite possible that Kayser's own settings on the secondary standards may contain systematic errors greater than the differences in the "measurements of the same sharp line on different plates." However, the fact remains that in the determinations of either the secondary or the tertiary standards, or both, *there are systematic errors greater than the accidental errors of measurement.*

(*b*) *The determination of stellar radial velocities.* In this

* *Astrophysical Journal* XXXII. 215–216. † *Ibid* XXXII. 217–225.

work systematic errors of measurement are more likely to occur than in any other involving the measurement of spectra, because the spectra measured—the star spectrum with its usually diffuse absorption lines, and the comparison spectrum with its strong emission lines—are so different in character. Furthermore, since the lines of the star spectrum often differ greatly in appearance and are in regions of the continuous spectrum of different intensity, systematic differences in velocity for the various lines are likely to be found, and since the star spectra are on a very small scale, these may represent variations of several kilometres per second. Such differences have been found, and though there are plausible physical explanations which one can give, such as electrical or magnetic effects, pressure effects, the presence of other bodies or of a hazy envelope about the star having a different motion, etc., yet it would be well before employing such theories to eliminate the possibility of systematic errors of measurement.

(*c*) *The comparison of various regions in the sun with one another and with standard spectra.* Much of this work depends on comparative measurements of spectra of different character, and, as pointed out above, is therefore liable to contain systematic error. Among the more important investigations in this field are some of those carried out at Mount Wilson Solar Observatory, on the displacements of the spectrum lines at the sun's limb*, and the motions of calcium vapor in the solar atmosphere† and over special regions in the sun.‡ The accidental errors of measurement in this work are extremely low, a precision of ·0001 Å being aimed at, and such being the case it would be well worth while to test for systematic errors which may well exceed this small quantity. Furthermore, in deciding whether the interesting results observed in these researches are due to pressure or to convection very accurate references to laboratory comparison spectra were necessary, and the spectra compared being widely different the decisions may have been affected by systematic error. Even

*Walter S. Adams, *Astrophysical Journal*, XXXI., 30-61.

†Charles E. St. John, *Ibid*, XXXII, 36-82.

‡Charles E. St. John, *Ibid*, XXXIV, 57-78.

so may be affected the results derived from the comparison of "enhanced" and "arc" lines in the same spectrum.*

(*d*) *The determination of the rate of the solar rotation.* The method chiefly used at present in the investigation of the rate of the sun's rotation, is that employed by Adams† at the Mount Wilson Solar Observatory, namely, the measurement of the spectral line displacements in adjacent simultaneously taken photographs of the spectra from opposite ends of a diameter of the sun's disc. These measurements differ from those made in the investigations mentioned above, in that the relative positions of *the same spectral lines in two presumably similar spectra* are sought, and consequently it is not so easily imagined, as in the case where *two different spectra* are compared, how systematic errors of measurement may happen. Nevertheless, it was in connection with this very problem that I first suspected the presence of such errors. In 1909 I measured a few plates of the solar rotation effect which I made with the twenty-three foot Littrow spectrograph using a plane grating which apparently on account of curvature of the lines‡ produced spectra of very poor definition. The spectrum lines were not sharp and the continuous spectrum was nebulous. From my measurements of from 30 to 80 lines on each of three plates, I noted that the greater proportion of the lines giving the largest values of the measured displacements were the broader and more fuzzy lines or those very close to other lines or to nebulous regions of the spectrum. A few scattered measurements on other plates seemed to confirm this observation. Measurements of one of these plates were published along with a description of the Spectrograph§ simply to illustrate the method, but even from these 80 measurements the tendency for the broader and more diffuse lines to give larger values for the displacement is noticeable. The mean velocity-equivalent of the measured displacements is 1·77 km. per second, and of the 9 lines with

*Walter S. Adams, "Some results of a study of the spectra of Sirius, Procyon and Arcturus with high dispersion," *Astrophysical Journal*, XXXIII., 64–71.

†*Ibid.* XXVI., 203; XXIX., 110; XXVII. 213.

‡De Lury, JOURNAL ROYAL ASTRONOMICAL SOCIETY OF CANADA, V., 26–32.

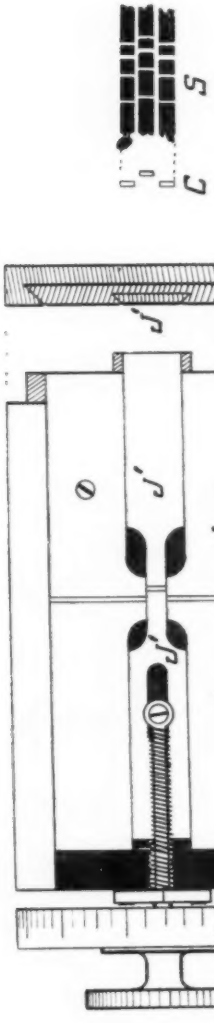
§*Report of the Chief Astronomer*, 1909, 255.

values greater than 1·90 km. per second, 4 are exceptionally broad or fuzzy lines, 1 is in a nebulous region and another is very close to another spectrum line, as follows; 4163·818, fuzzy, 1·95 km.; 4199·257, fuzzy, 2·13, and 1·95 km.; 4236·279, near 4236·112, 1·92, and 1·94 km.; 4246·966, broad and fuzzy, 1·94 km.; 4271·325, broad and fuzzy, 1·91 km.; (4271·934, broad and fuzzy neighboring line gives a value nearly as great, 1·87 km.); 4288·310, nebulous region, 1·98; the other three lines appear to be average lines. These measurements with the others mentioned above certainly warranted the suspicion that the broader and more nebuluos lines gave larger values, and so much was I impressed by them that my suspicions extended to the measurements of Adams on the rotation (*loc. cit.*) values for the two very broad and shaded lines H_α and λ 4227, which he found to give larger values for the rate of the sun's rotation than those obtained from the narrower absorption lines. I felt the necessity of making measurements to test these suspicions but thought it better to wait until a new grating giving sharper spectrum lines was obtained. Consequently, when work with the new grating was well under way and some measurements were made which still showed systematic tendencies, particularly some comparative measures by different persons, I proposed to make tests for systematic errors of measurement to be carried out in connection with the measurements of the plates of the solar rotation effect, in the hope that these errors if they actually existed could be eliminated and also that light might be thrown on my suspicions as to the reality of the results obtained by Adams regarding the systematically different displacements of various lines. I accordingly devised a method of attacking the problem, a description of which, together with some preliminary measures, constitutes the the remainder of this paper.

The method consists essentially in introducing by mechanical means on the spectrum lines under investigation an arbitrary displacement which is the same for all the lines, and which should yield, in the absence of systematic errors, the same measured values within the limits of the accidental errors, and for a large

series of observations the same means for all the lines whether measured by the same or different observers; if the means of the measured values in such a series are not close to the same value, then systematic errors are present, and their magnitude and nature can be determined from the differences.

The arbitrary displacement may be introduced by taking the photograph of one spectrum first, then shifting the plate-holder and taking the photograph of the other spectrum. The plate-holder may be moved between stops or moved by means of a micrometer screw. The method is very satisfactory if one is not anxious to have the displacements on a series of plates identically the same. For several reasons, however, I desired the latter condition and accordingly devised a second method of obtaining the displacement. This method consists in the taking of spectra from two parallel slits whose widths and distances apart are adjustable and may be kept constant for a series of plates, the distance apart of the slits governing the displacement of the spectra. To reproduce the configuratian of the "rotation spectra" taken here, I had the "double-slit" constructed in the form shown in the Figure, which represents a bird's eye view of the apparatus. *F*, is a brass frame with bevelled runs in which the slit-jaws, *J*, *J*, work. These jaws are also milled with bevelled runs in which the smaller jaws J^1, J^1, slide. The slit edges of all these jaws are parallel, and they are bevelled back, leaving their sharp edges in the plane of their faces. The smaller jaws were set in the larger and their edges polished simultaneously to insure parallelism, the polishing being done on plate-glass with the finest emery. One of the jaws, *J*, is screwed to *F* in a fixed position, while the other may be slid back and forth in *F* by means of the micrometer, *M*, with the aid of a coiled spring as in ordinary spectograph-slits, and the distance between the jaws may be read in ten-thousandths of an inch. The slit between the jaws, J^1, J^1, may be adjusted to any desired distance to either side of the slit between the larger jaws. The widths of the two slits will be the same if they are adjusted so that they close simultaneously, since when jaw *J* is moved by the micrometer it carries with it one of the smaller


S
C
J'
J
F
J'
J
J'
J
F
M

jaws. A mask is next placed over the slits to give the configuration *C*. The double-slit replaces the ordinary slit of the spectrograph, and the spectra taken are represented by *S*. A precisely similar mask is used in taking the rotation spectra, so that the widths of the strips of spectra and the distances apart are exactly the same. Both spectra are taken from the same distance inside the limb of the sun, so that the only difference between them lies in the fact that in the rotation spectra the displacement of the spectral lines is due to the rotation of the sun, while in the double-slit spectra the displacement is caused by the displacement of the slits and is, therefore, the same for all lines. Measurements of the latter should therefore reveal the exact nature of the errors of measurement of the former. In a somewhat similar manner the double-slit may be employed to investigate the errors of measurement in connection with the other problems mentioned above. If the double-slit is to be used very much it will be found advantageous to provide a micrometer attachment to the right-hand jaw, J^1, so that its distance from the slit made by the larger jaws may be readily adjusted. For use in the present investigation the displacement was fixed at about 0·07mm., the value of the displacement at the equator on the rotation plates at λ 4250, the region chosen because it was that employed by Adams in his work on the Solar Rotation and is the common region selected by the International Union for Co-operation in Solar Research.

In making the measurements the large Toepfer measuring machine of the Observatory was used. This instrument has a thread 30cm. (12 in.) long, and of 0·5 mm. pitch and is capable of measuring over the whole range of the 12 in. plates taken in the Solar Spectrograph. The micrometer reads to microns, and estimations to one-tenth of this value, *i. e.*, to one ten-thousandth of a mm., (0·0001 mm.) may be made. The measures given in the following Tables are expressed in this unit. All measurements of the displacement of any line consist in taking the difference between the means of 4 settings on the line in the central strip of spectrum and the mean of 2 settings on the line in each of the two outside strips; when all the lines in question are

measured, the plate is turned through 180° (always face up) and the measurements repeated, the run of the micrometer screw being in the opposite direction: the mean of the means from the two runs d' and d'', for each line is the measured displacement, d, for that line, and it thus depends on 16 settings. Before giving the measurements of the arbitrary displacement plates, I will present some results illustrating the differences in the measures of the same lines by different observers. In the Tables, d denotes displacement, and r the residual of the displacement obtained by subtracting the mean from each value; $p.\ r.$ denotes the probable residual (for the r's in question).

TABLE I.—PLATE, L570a, (ROTATION EFFECT).

Line / Measurer	4548·938		4558·827		4564·939		4571·275		Means	
	d	*r*	*d*	*r*	*d*	*r*	*d*	*r*	*d*	*r*
Plaskett	533	− 4	537	+ 14	540	+ 25	545	+ 21	539	+ 14
	(571	+ 34)	(553	+ 30)	(506	+ 51)	(577	+ 53)	(568)	
Harper	563	+ 26	515	− 8	510	− 5	510	+ 26	535	+ 10
Parker	550	+ 13	540	+ 17	500	− 15	520	− 4	528	+ 3
Cannon	540	+ 3	552	+ 29	513	− 2	502	− 22	527	+ 2
Motherwell	543	+ 6	500	− 23	500	− 15	522	− 2	516	− 9
De Lury	493	− 44	496	− 27	526	+ 11	507	− 17	506	− 19
	(520	− 17)	(490	− 33)	(481	− 34)	(536	− 12)	(507)	
Means	537		523		515		524		525	

Note.—The bracketed values are duplicate measures previously made and whose peculiar differences made it desirable to have measurements made by other observers. All but the bracketed values are derived from measures made in only one position of the plate.

TABLE II.—L701f, ARBITRARY DISPLACEMENT BY DOUBLE-SLIT.

Line	4220·509, Fe, 3			4225·619, Fe, 3			4232·887, Fe, 2			4241·285, Fe Zr, 2			4246·996, Sc?, 5			Means		
Measurer	*d'*	*d''*	*d*	*d'*	*d''*	*d*	*d'*	*d''*	*d*	*d'*	*d''*	*d*	*d'*	*d''*	*d*	*d'*	*d''*	*d*
Plaskett	721	704	713	720	730	725	700	713	706	707	700	704	689	683	686	707	706	707
	(712	697	709)	(687	710	699)	(702	687	695)	(715	718	716)	(688	690	689)	(701	700	700)
Cannon	706	701	704	679	725	702	678	660	669	710	668	689	687	731	709	692	697	694
Parker	648	716	682	663	744	704	709	671	690	691	725	704	663	688	675	675	709	692
Harper	676	700	688	706	742	724	654	666	660	714	681	697	669	671	670	684	692	688
De Lury	609	682	676	733	701	717	649	659	654	710	702	700	653	690	671	683	687	685
	(669	731	700)	(741	726	734)	(691	638	664)	(648	652	650)	(715	660	688)	(693	681	687)
Stewart	658	687	673	656	712	684	683	649	666	663	669	666	705	658	682	673	675	674
Means *d'*	680			693			679			699			678			686		
Means *d''*		698			726			669			689			686			694	
Means *d*			689			709			674			694			682			690

Note.—The bracketed values, previously obtained, suggested the advisability of repeating the measurements and having other observers make them also. The bracketed values are not included in taking the means. The values obtained for the whole exposure L701f at the previous measurement, were, Plaskett, 702; De Lury, 686.

TABLE III.—L641, ARBITRARY DISPLACEMENT BY MOVING THE PLATE-HOLDER

Measured by DeLury

Line	Int.	Width	Remarks	L641a				L641b				L641c				L641d			
				d'	d''	d	v	d'	d''	d	v	d'	d''	d	v	d'	d''	d	v
1. 5506·035, Mn, 1.		1286, weak		1053	906	980	+119	641	665	653	+53	658	771	714	-40	999	1037	1018	- 8
2. 5507·000, Fe, 7.		1776, broad, strong		801	841	851	10	611	644	628	+28	792	729	760	- 31	999	1037	1018	- 8
3. 5525·705, Fe, 4.		1332, fine		801	851	820	35	644	615	630	+30	691	728	709	- 54	1005	1105	1055	+29
4. 5528·041, Mg, 8.		2816, shaded, fuzzy		704	980	837	24	627	548	588	12	839	673	756	- 7	951	998	974	- 52
5. 5544·157, Fe, 2.		1050, fine		874	844	859	- 2	601	614	608	+ 8	742	678	710	- 53	1032	1089	1060	+31
6. 5562·933, Fe, 2.		1119, fine		827	853	840	- 21	551	648	600	0	742	757	749	14	1013	957	985	41
7. 5570·320, Fe, 4.		1688, strong		833	824	829	- 32	587	642	615	+15	783	814	798	+35	969	1033	1001	- 25
8. 5578·946, Ni, 1.		1142, fine		902	892	897	+ 36	544	601	573	27	782	729	755	- 8	1060	1042	1051	+25
9. 5582·198, Ca, 4.		1410, strong		848	819	833	28	602	608	605	+ 5	729	716	722	- 4	1013	977	995	- 31
10. 5590·343, Ca, 3.		1544, fine		931	938	935	+ 74	563	588	576	- 24	741	776	758	- 5	1056	1080	1068	+42
11. 5618·858, Fe, 1.		1072, fine		855	875	865	+ 4	585	496	541	59	787	909	848	+85	1095	1120	1107	+81
12. 5634·171, Fe, 3.		1295.		822	710	766	- 95	596	664	630	+30	779	773	776	+13	953	943	951	- 75
13. 5638·488, Fe, 3.		1452.		888	911	900	+ 39	576	607	592	8	704	818	806	+43	1012	1008	1010	- 16
14. 5655·715, Fe, 2.		1300,		750	905	827	+ 34	580	568	574	- 26	857	823	840	+77	1091	998	1044	+18
15. 5658·097, V, 2.		1329.		655	813	734	- 127	611	638	625	+25	822	749	785	+22	982	1028	1005	- 21
16. 5662·744, Fe, 4.		1343, weak cont.		885	822	852	- 9	592	668	630	+30	744	788	766	+ 3	1046	1103	1074	+48
17. 5682·860, Na, 5.		1536,	spectrum	971	849	910	+ 49	585	731	660	+60	744	778	761	- 2	988	974	981	- 45
18. 5688·436, Na, 6.		1808,		862	822	842	19	525	607	566	- 34	767	784	775	+12	1027	1099	1063	+37
19. 5690·646, Si, 3.		1090, narrow, weak		923	1039	981	+120	495	528	512	- 88	714	688	701	- 62	1030	1012	1021	- 5
			d'	855				585				764				1018			806
		Mean	d''		867				615				762				1034		820
			d			861				600				763				1026	813

Table IV.—L 699, Arbitrary Displacement, by Double-Slit.

Measured by DeLury

Line		L699a			L699b			L699c			L699d			L699e			L699f			Means			
		d'	*d''*	*d*	*d'*	*d''*	*d*	*d'*	*d''*	*d*	*d'*	*d''*	*d*	*d'*	*d''*	*d*	*d'*	*d''*	*d*	*d'*	*d''*	*d*	*r*
1, 4196·699,	La, 2	654	639	647	646	730	688	736	795	764	715	721	718	663	719	691	721	689	708	690	716	703	+ 10
2, 4197·257,	CN, 2	614	655	634	798	797	798	711	704	708	675	719	697	633	780	707	690	674	682	687	721	704	+ 11
3, 4216·130,	CN, 2	723	679	701	678	695	686	727	678	702	641	748	695	713	730	721	743	740	741	704	712	708	+ 17
4, 4220·509,	Fe, 3	626	638	632	724	725	725	710	777	744	729	681	705	705	670	688	654	715	685	691	701	696	+ 4
5, 4225·619,	Fe, 3	726	743	735	634	631	632	793	711	752	641	638	639	667	692	679	742	712	727	700	688	694	+ 1
6, 4232·887,	Fe, 2	696	668	682	697	687	692	755	731	743	675	675	675	666	689	678	611	660	635	683	685	684	− 9
7, 4241·285,	Fe-Zr, 2	711	666	688	671	646	658	611	655	633	685	781	733	720	735	727	850	767	808	708	708	708	+ 15
8, 4246·996,	Sc, 5?	642	637	639	660	628	644	693	727	710	604	747	676	689	729	709	716	792	754	667	710	689	− 4
9, 4257·815,	Mn, 2	642	743	693	604	595	599	660	701	650	657	713	685	631	722	677	705	767	736	640	707	673	− 20
10, 4258·477,	Fe, 2	687	698	692	673	673	673	699	705	702	712	653	683	705	672	688	664	733	698	690	689	689	− 4
11, 4266·081,	Mn, 2	641	635	638	696	738	717	626	726	676	722	686	704	682	670	676	656	689	673	671	691	681	− 12
12, 4268·915,	Fe, 2	590	589	589	719	659	689	690	603	644	708	681	694	650	696	673	704	686	695	677	653	665	− 28
13, 4276·836,	Zr, 2	713	717	715	660	680	670	610	658	634	724	724	724	698	705	702	710	675	692	686	692	689	− 4
14, 4290·377,	Ti, 1	716	771	744	764	747	755	697	719	708	730	663	697	700	682	691	640	715	678	708	716	712	+ 19
15, 4291·630,	Fe, 2	733	761	747	670	657	664	670	663	667	740	683	711	719	692	700	668	709	688	700	692	696	+ 3
Means	*d'*	674			686			689			691			683			699			687			±10·7
	d''		683			686			704			701			706			715			699		
	d			678			686			696			696			694			707			693	

Table V.— L701 Arbitrary Displacement, by Double-Slit

Measured by DeLury

Line			L701a			L701b			L701c			L701d			L701e			L701f			Means			
			d'	d''	d	d'	d''	d	d'	d''	d	d'	d''	d	d'	d''	d	d'	d''	d	d'	d''	d	r
1, 4196·999,	La,	2	641	606	624	673	736	704	663	616	640	700	742	721	675	724	699	678	757	717	671	697	684	− 10
2, 4197·257,	CN,	2	647	586	616	654	748	701	622	610	616	758	785	772	674	675	675	586	620	603	657	671	664	− 30
3, 4216·136,	CN,	2	651	740	696	696	675	686	728	713	720	672	692	682	699	732	714	703	726	715	685	719	702	+ 8
4, 4220·509,	Fe,	3	762	728	745	748	704	726	707	673	690	642	667	654	687	687	687	669	731	700	702	698	700	+ 6
5, 4225·619,	Fe,	3	686	660	673	754	811	782	729	743	737	791	655	723	747	709	723	741	726	733	740	716	728	+ 34
6, 4232·887,	Fe,	2	707	651	679	714	736	725	699	702	700	724	713	719	706	670	688	691	638	665	713	685	699	+ 5
7, 4241·285,	Fe-Zr,	2	718	755	736	620	681	651	693	737	715	756	747	751	656	672	664	648	652	650	683	707	695	+ 1
8, 4246·996,	Sc,	5?	666	647	654	641	671	656	674	778	726	636	771	704	646	681	664	715	660	687	629	701	665	− 29
9, 4257·815,	Mn,	2	675	705	690	705	702	703	744	699	722	623	660	641	685	719	702	816	727	772	718	712	715	+ 21
10, 4258·477,	Fe,	2	697	709	703	694	651	673	698	714	706	666	683	675	682	695	688	680	696	688	687	691	689	− 5
11, 4266·081,	Mn,	2	673	677	675	618	614	616	753	705	759	701	748	724	635	636	636	641	650	645	680	682	681	− 13
12, 4268·915,	Fe,	2	655	663	659	665	741	703	636	662	649	682	652	667	700	701	700	633	629	631	661	675	668	− 29
13, 4276·836,	Zr,	2	746	749	747	697	703	700	737	725	730	709	695	687	668	656	662	667	706	686	703	701	702	+ 8
14, 4290·377,	Ti,	1	752	733	743	733	742	737	716	711	714	736	735	735	734	727	730	663	686	678	724	722	723	+ 29
15, 4293·630,	Fe,	2	724	710	717	636	686	661	727	676	701	659	612	636	711	672	692	710	738	724	694	682	688	− 6
Means	d'		693			687			702			697			691			683			690			± 15·4
	d''			687			711			702			701			683			689			697		
	d				690			699			702			699			690			686			694	

Table VI.

Errors of Setting.

L699, Arbitrary Displacement by Double-Slit.

Line			Algebraic Means				Arithmetic Means				Means
			1st	2nd	3rd	4th	1st	2nd	3rd	4th	
1, 4196·699,	La,	2	− 7	+13	− 6	− 1	15	26	12	18	18·6
2, 4197·257,	CN,	2	− 0	+ 7	0	−11	28	25	25	20	24·5
3, 4216·136,	CN,	2	+ 7	− 1	+ 8	− 3	40	23	30	31	31·0
4, 4220·509,	Fe,	3	+ 9	+ 2	− 2	− 3	24	16	22	23	21·3
5, 4225·019,	Fe,	3	+20	−12	− 8	0	25	20	28	20	23·3
6, 4232·887,	Fe,	2	−15	+12	− 4	+ 6	21	17	20	14	18·0
7, 4241·285,	Fe-Zr,	2	0	− 7	+ 6	0	25	12	18	21	18·8
8, 4246·996,	Sc,	5?	−14	+ 5	− 7	+18	25	17	21	19	20·5
9, 4257·815,	Mn,	2	+10	− 4	− 6	0	34	19	13	24	22·5
10, 4258·477,	Fe,	2	+ 3	− 2	− 2	+ 1	21	13	12	15	15·3
11, 4266·081,	Mn,	2	−14	+ 1	+12	+ 2	21	16	19	14	17·5
12, 4268·015,	Fe,	2	− 3	−14	+ 4	+12	21	22	11	21	18·8
13, 4270·830,	Zr,	2	− 4	− 7	− 6	+16	14	13	16	20	15·8
14, 4290·377,	Ti,	1	+ 3	0	− 2	− 2	14	18	14	13	14·8
15, 4291·630,	Fe,	2	− 2	− 8	+ 8	+ 3	14	14	18	10	14·0
	Means		− 1	− 1	0	+ 2	23	18	18·6	19	19·0

Note.—The above numbers are the means—algebraic (with regard to sign), and arithmetic (without regard for sign)—of the 1st, 2nd, 3rd and 4th settings on the lines in the central strips of the six exposures, L699a to L699f, measured both ways; each mean for each line is therefore the mean of 12 settings made at different times.

TABLE VII.—SUMMARY OF MEASUREMENTS OF ARBITRARY DISPLACEMENTS, PLATES L699 AND L701

Measured by DeLury.

Line	Int.	Width	Remarks		L699 (a)	(b)	(c)	(d)	(e)	(f)	L701 (a)	(b)	(c)	(d)	(e)	(f)	Means d	r	$p.r.$
1, 4195·599,	La,	2,	2320	Diffuse	d	647	688	704	718	691	708	624	704	640	721	699	717	694		
				strong	r	− 31	+ 2	+ 68	+ 22	− 3	+ 1	− 66	+ 5	− 62	+ 22	+ 9	+ 31		0	± 26·7
2, 4197·257,	CN,	2,	1660	Asymmetrical	d	634	708	708	697	707	682	616	701	616	772	675	603	684		
				weak	r	− 44	+ 112	+ 12	+ 1	+ 13	− 25	− 74	+ 2	− 86	+ 73	− 15	− 83		− 10	42·7
3, 4216·136,	CN,	2,	2052	Asymmetrical	d	701	686	702	695	721	741	696	686	720	682	714	715	705		
					r	+ 23	0	+ 6	− 1	+ 27	+ 34	+ 6	− 13	+ 18	− 17	+ 24	+ 29		+ 9	14·6
4, 4220·509,	Fe,	3,	1710	Good, strong	d	632	725	744	705	688	685	745	726	690	654	687	700	698		
				narrow	r	− 46	+ 30	+ 48	+ 9	− 6	− 22	+ 55	+ 27	− 12	− 45	− 3	+ 14		+ 4	23·9
5, 4225·619,	Fe,	3,	1090	Good, strong	d	735	632	752	639	679	727	673	782	737	723	723	733	711		
				near 4227	r	+ 57	− 54	+ 56	− 57	− 15	+ 20	− 17	+ 83	+ 35	+ 24	+ 33	+ 47		+ 17	34·0
6, 4232·887,	Fe,	2,	1634	Fine, good	d	682	692	743	675	678	635	679	725	700	719	688	665	692		
					r	+ 4	+ 6	+ 47	− 21	− 16	− 72	− 11	+ 26	− 2	+ 20	− 2	− 21		− 2	19·7
7, 4241·285,	Fe-Zr,	2,	1409	Fine, weak	d	688	658	633	733	727	808	736	651	715	751	664	650	701		
					r	+ 10	− 28	− 63	+ 37	+ 33	+ 101	+ 46	− 48	+ 13	+ 52	− 26	− 36		+ 7	34·4
8, 4246·960,	Sc,	5,	2500	Strong, broad	d	639	644	710	676	709	754	654	656	720	704	664	687	678		
					r	− 30	− 42	+ 14	− 20	+ 15	+ 47	− 36	− 43	+ 24	+ 5	− 20	+ 1		− 16	22·7
9, 4257·815,	Mn,	2,	1040	Diffuse	d	693	599	650	685	677	730	690	703	722	641	702	772	694		
				weak	r	+ 15	− 87	− 40	− 11	+ 17	+ 29	0	+ 64	+ 20	− 58	+ 12	+ 86		0	34·6
10, 4258·477,	Fe,	2,	1925	Broad	d	692	673	702	683	688	698	703	673	706	675	688	688	689		
				strong	r	+ 14	− 13	+ 6	− 13	− 6	− 9	+ 13	− 26	+ 4	− 24	+ 2	+ 2		− 5	9·7
11, 4266·081,	Mn,	2,	1710	Fair	d	638	717	676	704	676	673	675	616	759	724	666	645	681		
				weak	r	− 40	+ 31	− 20	+ 8	− 18	− 34	− 15	− 83	+ 61	+ 25	− 24	− 41		− 13	27·8
12, 4268·915,	Fe,	2,	1480	Good	d	589	689	649	694	673	695	659	703	649	667	700	631	667		
				edges weak	r	− 89	+ 3	− 47	− 2	− 21	− 12	− 31	+ 4	− 53	− 32	+ 10	− 55		− 27	29·0
13, 4276·836,	Zr,	2,	1590	Diffuse	d	715	670	634	724	702	692	747	700	730	687	662	686	695		
					r	+ 37	− 16	− 62	+ 28	+ 8	− 15	+ 57	+ 1	+ 28	− 12	− 28	0		+ 1	22·8
14, 4290·377,	Ti,	1,	2365	Broad	d	744	785	708	697	691	678	743	737	714	735	730	678	717		
				edges sharp	r	+ 66	+ 69	+ 12	+ 1	− 3	− 29	+ 53	+ 38	+ 12	+ 36	+ 40	− 8		+ 23	28·1
15, 4291·630,	Fe,	2,	1900	Broad	d	747	664	667	711	700	688	717	661	701	636	692	724	692		
					r	+ 69	22	− 29	+ 15	+ 6	− 19	+ 27	38	− 1	− 6	+ 2	+ 38		− 2	± 25·5
				Mean	d	678	680	696	690	694	707	690	699	702	699	690	686	694		± 20·1
				Probable residual =	$p.r.$	31·0	33·1	20·2	15·5	11·3	27·9	29·5	29·7	26·5	27·2	14·8	29·3	Mean $p.r.$		± 25·5

Probable residual of the displacement for a single exposure = ± 8·0

TABLE VIII—SUMMARY OF MEASUREMENTS OF ARBITRARY DISPLACEMENTS, PLATES L699 AND L701.

Measured by Plaskett.

	Line	Int.	Width	Remarks		L699 (a)	(b)	(c)	(d)	(e)	(f)	L701 (a)	(b)	(c)	(d)	(e)	(f)	Means d	r	$p.e.$
1.	4190·500.	La.	2.	2020	Diffuse	d	683	692	710	704	709	700	693	717	683	693	711	704	700		
					Strong	r	− 9	− 2	+ 8	+ 13	+ 5	+ 3	− 15	+ 11	− 23	− 1	+ 14	+ 2		0	± 7·6
2.	4197·257.	CN.	2.	1660	Asymmetrical	d	706	716	714	705	719	700	717	702	715	696	681	699	706		
					Weak	r	+ 14	+ 22	+ 12	+ 14	+ 15	− 3	+ 9	− 4	+ 9	+ 2	− 16	− 3		+ 6	8·4
3.	4216·136.	CN.	2.	2052	Asymmetrical	d	688	710	680	696	706	702	704	709	699	686	703	705	700		
						r	− 4	+ 10	− 13	+ 5	+ 2	− 1	+ 4	+ 3	− 7	+ 5	+ 6	+ 3		0	5·2
4.	4220·500.	Fe.	3.	1710	Good, strong	d	686	693	705	688	695	704	710	694	692	696	706	709	698		
					Narrow	r	− 6	− 0	+ 3	− 3	− 9	+ 1	+ 2	− 12	− 14	+ 2	+ 9	+ 7		− 2	5·0
5.	4225·619.	Fe.	3.	1990	Good, strong	d	703	688	700	686	705	704	696	708	710	696	683	699	698		
					Near 4227	r	+ 11	− 6	+ 2	− 5	+ 1	+ 1	− 12	+ 2	+ 4	+ 2	− 14	− 3		+ 2	4·8
6.	4232·887.	Fe.	2.	1634	Fine, good	d	689	677	695	704	684	696	715	707	703	689	705	695	697		
						r	3	17	− 7	+ 13	20	− 7	− 7	+ 1	− 3	− 5	+ 8	− 7		− 3	6·8
7.	4241·285.	Fe-Zr.	2.	1400	Fine, weak	d	692	708	704	696	691	710	710	711	707	702	689	716	703		
						r	0	+ 14	+ 2	+ 5	− 13	+ 7	+ 2	+ 5	+ 1	+ 8	− 8	+ 14		+ 3	5·8
8.	4246·096.	Sc.	5.	2500	Strong, broad	d	689	675	693	682	695	700	707	699	701	685	687	689	692		
						r	− 3	19	− 9	9	9	− 3	− 1	− 7	5	− 9	− 10	− 13		− 8	6·4
9.	4257·815.	Mn.	2.	1640	Diffuse	d	702	675	693	675	717	708	713	711	713	700	698	698	700		
					Weak	r	+ 10	19	− 9	− 10	+ 13	+ 5	+ 5	+ 5	+ 7	+ 6	+ 1	− 4		0	6·7
10.	4258·477.	Fe.	2.	1925	Broad	d	691	704	697	691	691	703	715	705	716	689	685	701	699		
					Strong	r	− 1	+ 19	− 5	0	13	0	+ 7	− 1	+ 10	− 5	− 12	− 1		− 1	5·1
11.	4266·081.	Mn.	2.	1710	Fair	d	679	706	721	682	707	712	698	706	721	700	687	689	701		
					Weak	r	− 13	+ 12	+ 19	− 9	+ 3	+ 9	− 10	0	+ 15	+ 6	− 10	− 13		+ 1	7·3
12.	4268·915.	Fe.	2.	1480	Good	d	681	704	698	682	717	707	712	711	708	696	696	710	702		
					Edges weak	r	− 11	+ 10	4	− 9	+ 13	+ 4	+ 4	+ 5	+ 2	+ 2	− 1	+ 8		+ 2	5·1
13.	4276·836.	Zr.	2.	1590	Diffuse	d	691	691	708	684	700	686	711	705	698	702	712	709	700		
						r	− 1	3	− 6	7	− 4	17	+ 3	1	− 8	+ 8	+ 15	+ 7		0	5·8
14.	4290·377.	Ti.	1.	2365	Broad	d	699	686	705	699	706	696	703	695	713	693	709	704	700		
					Edges sharp	r	+ 7	− 8	+ 3	+ 8	+ 2	− 7	− 5	− 11	+ 7	+ 1	− 12	+ 2		0	4·8
15.	4291·630.	Fe.	2.	1900	Broad	d	700	681	695	686	715	710	713	709	711	684	706	700	701		
						r	+ 8	13	− 7	− 5	+ 11	+ 7	+ 5	+ 3	+ 5	− 10	+ 9	− 2		+ 1	± 5·8
					Mean	d	692	693	702	691	704	703	708	706	706	694	697	702	700		± 6·0
					Probable residual	$p.e.$	9·1	6·0	6·4	7·2	4·6	5·0	4·2	6·8	3·9	7·4	5·0	5·6	Mean $p.e.$		± 5·9

Probable residual of the displacement for a single exposure = ± 4·1.

The discussion of the results given above can best be made under the headings of the various classes of errors investigated:

Systematic differences in the measurements by different measurers. A glance at Tables I. and II. reveals the fact there are systematic differences in the measurements made by different persons, and in the general trend the results indicate that those who have had considerable experience in the measuring of stellar radial velocity spectrograms get higher values than those who have had little experience in the measurement of spectra. The differences between the highest and lowest values of the mean displacements are, from Table I., 33, *i. e.*, 0·0033 mm., and from Table II., the same value, 33, representing differences of 6·3 per cent, and 4·8 per cent respectively. These differences are equivalent to differences of 0·13 and 0·10 km. per second in the determination of the equatorial rate of the sun's rotation from similar displacements. This is a striking difference, and the question arises: Which is more nearly the true value, the high measurement, or the low one? and further, what is the true value?—for obviously it is not safe to take the mean value of all the measurements when such systematic errors occur. From the results of a large series of measurements, involving double measures on 12 different exposures (summarized in Tables VII. and VIII.) Mr. Plaskett's measurements are seen in the mean to be greater than mine by 6 in a displacement of about 700. This difference is systematically in the same direction with the exception of the measurements for 2 out of the 12 exposures, and 3 out of the 15 lines, one line giving the same mean. This difference corresponds to 0·02 km. per second, a very small quantity, yet it is in the hundredths of a kilometer per second that nearly all of the interest in the determination of the solar rotation lies at the present time in view of the many interesting results obtained by Adams and Halm. It is consequently of considerable importance in such investigations to make allowance and correction for the systematic differences in the measurements of different persons.

Systematic differences depending on the configuration measured. A very curious systematic difference in the measurement of the

displacements presents itself when measures are made one way and the plate is reversed and measured in the other direction, the face of the plate being up in all measurements. This difference, which apparently is in the same sense for all observers, is exhibited in Table II. where measures of 6 lines on one exposure are given for six different measurers, and in Tables III., IV. and V. where my own measurements of 16 different exposures are recorded. It will be seen from Table II. that, with the exception of Mr. Plaskett's measurements which in this Table do not show the effect, the first measurement, d', is systematically smaller than d'', the second measurement, for each line with one exception, and for each observer. In the mean, $d'' - d' = 694 - 686 = 8$, a difference corresponding to 0·023 km. per second. In my larger series of measurements this peculiarity is even more strikingly shown. In the values for L641, Table III., we have, $d'' - d' = 820 - 806 = 14$, which corresponds in the region of the spectrum measured, to about 0·04 km. per second. For L699, Table IV., the difference, $d'' - d' = 699 - 687 = 12$, corresponds to 0·03 km. per second; and for L701, Table V., the difference, $d'' - d' = 697 - 690 = 7$, corresponds to 0·02 km. per second. In all cases for the measurements of d' the configuration of the lines as seen in the eye-piece of the measuring machine, was, | | | while for the measurements d'' it was the opposite, | | |. Furthermore, the carriage was advanced so that the spider-line of the eye-piece always passed over the central line first, and the four settings were made on the central line before passing to the two outside lines. It is not likely that the fact that the d'' measures were made subsequently to the d' measurements has anything to do with this remarkable difference; (yet there is the possibility of one's measurements becoming more "liberal" as he continues to measure — a "fatigue" effect) nor are temperature differences in the micrometer screw caused by the presence of the measurer while securing the values of d' sufficient to account for the larger values of d''. Nor does the direction of turning the screw account for the difference,

for in the measurements of L641 the screw was turned in the opposite direction from that used in the other measurements, the central strip being displaced to the red of the two outside strips in it and to the violet side of the spectrum in plates L699 and L701: to get the same configuration in the microscope for the d' measures it was therefore necessary to start the readings from the opposite ends of the scale for the two opposite displacements. It thus appears that the difference does not depend on the direction of turning of the screw but on the configuration of the three lines visible in the eye-piece of the measuring machine. Thus, the most plausible explanation of the difference, it seems to me, is a "right-handed and left-handed" effect. The fact that in d' the lines in the two outside strips appear to the right of the line in the central strip, and that in d'' the opposite is the case may produce effects on the eye resulting in this curious difference in the measures of the displacement. I try to eliminate such a thing as "muscular memory" by taking a fresh grip on the turning wheel before each setting. Further-more it must be understood that the magnification of the microscope is so great that when a setting is made on one of three lines, the observer is *apparently* not conscious of the presence of the other lines; the above considerations would seem to indicate that the other lines exert some small influence over him nevertheless. In Adams' work on the rotation two strips of spectra were employed, so that the configuration of the lines would be the same in both positions of the plate, and consequently the measured displacements are liable to be too large or too small from such an effect as is here shown to be present. This effect is so large that it must be eliminated from the measurements.

Systematic differences for different lines.

From Table VII. it will be seen that there is a tendency towards negative residuals in my measurements in the cases of lines 8, 11 and 12; and positive residuals for the lines 5 and 14. In Mr. Plaskett's results the tendency to negative residuals occurs in the cases of lines 6 and 8, and positive residuals for lines 2 and 7. Nearly all of these lines have some exceptional characteristic;—

line 2, 4197·257, CN, is a weak line slightly diffuse and shaded asymmetrically; line 5, 4225·619, Fe, is a good strong line with slightly diffuse edges and it is near the strong, broad and nebulous line of Ca, 4227, which appears in the field of the microscope during the measurements of line 5; line 6, 4232·887, Fe, is a narrow strong line and a good one for measuring; line 7, 4241·285, Fe–Zr, is narrow and weak; line 8, 4246·996, Sc, is a strong and very broad line but it has sharp edges and is therefore a fairly good line to measure; 11, 4266·915, Mn, 2, is a weak line; line 12, (4268·915, Fe, is a narrow line with edges slightiy diffuse; line 14 4290·377, Ti, is a very broad line with its edges sharp and strong. As seen in the last paragraph it seems very probable that the configuration of the line plays some part or has some slight effect on the measurements; such being the case it is reasonable to suppose that this effect will vary with lines of different character, and consequently the measured displacements may vary. I made measurements on three dense exposures of the Ca line 4227 to see if any exceptional effects were present such as those obtained for this line and for Hα by Adams in his solar rotation work. The errors of setting were very large and nothing definite could be found from so few measures. Such measures should be made, and preferably under the same conditions as the rotation plates were measured by Adams and Miss Lasby. The present results show, however, that there is a danger of systematic errors being present for the various lines, and the differences obtained for individual lines in the rotation work should be very carefully examined by the person making the measurements, at the time they are made preferably, to see if they are due to such systematic errors of measurement.

It will be seen from Tables VII. and VIII., that the probable residuals for the different lines differ greatly, and that my $p.r.$ is much greater than Mr. Plaskett's. This is probably due to the fact that the latter observer has had a great deal of experience in the measurement of the broad diffuse lines of stars spectra, and his eye is accustomed to smoothing out the irregularities in the lines due to the grain of the plate, and that I am still bothered

by it and have more difficulty in setting on the centres of intensity of the lines. It is likely that more experience will relieve me of much of this error. These errors are combined accidental and systematic, and probably when the systematic errors are removed the residuals will be greatly lessened.

Systematic errors in setting.

In Table VI. are given my errors of setting for the 4 settings on the lines in the central strips (measured both ways) of Plate, L699. The numbers are the means of the residuals, with regard to sign and without regard to sign, obtained by subtracting the mean of the 4 settings on any one line from each of the settings on that particular line and taking the means for each line. Though each line has its own peculiar arrangement of the positive and negative residuals for each of the 4 settings—quite striking in some cases—yet there seems to be no general systematic arrangement of these signs. The means without regard to sign show the peculiar and not unexpected result that the first settings are usually farthest from the mean, while the residuals for the other three settings are of about the same magnitude. This peculiarity may be lessened to some extent by viewing the lines as a whole more carefully before taking any settings. The mean error of setting is, $\pm$ 19·6, or about 0·002 mm., equivalent to nearly 0·056 km. per sec.

The above results were obtained in measurements of the simplest class, namely, the relative positions of the *same* lines, and where, therefore, systematic errors are not so likely to occur as in investigations where the relative positions of *different* lines are determined; yet, nevertheless, the results show the presence of systematic errors. It may be taken for granted, then, that similar and larger errors occur in other spectroscopic measurements. And since the errors are sufficiently large that their removal is desirable, a general method for the elimination of such errors is necessary. An obvious method of eliminating some of these errors is to make the configuration the same for each measurement. This may be accomplished in the

particular case examined above by means of a moveable slit which could be readily placed so that only one strip of spectrum could be seen at a time, and each measured in turn. In the general case, however, where different lines are compared, this would not remove the individual errors of each line, and would not remove any systematic errors of "memory" if they were present. The "double-slit" used above offers a more complete elimination of the difficulty as follows:

By means of the double-slit introduce a displacement, D, on the spectra whose normal displacement, d, is desired to be found. By making D much larger than d, it may be assumed (and this point could easily be tested by use of the double-slit) that the systematic errors in measuring $D + d$ are the same as for the measurement of D. Thus let the measured value of the displacement be $D + d + e$, then the measured displacement of D will be $D + e$, and the difference between the two measurements, $(D + d + e) - (D + e)$, will give the true value, d, of the displacement sought. The principle is precisely the same as the "method of differences" used in exact weighings. It would involve two parallell series of measurements, but the determination of $D + e$ would probably not need to be made so frequently as the determination of $D + d + e$, after one became somewhat fixed in his habits of measurement. In the investigation of the solar rotation this method could be readily applied. The displacements, d, in our work here range from a little less than 0·1 mm. down to nearly zero, so that by introducing a displacement $D = 1$mm. in all the rotation spectra the total displacements would be so nearly constant that very probably the systematic errors of measurement would be the same for all, and one determination of $D + e$ for spectra from 6 or 7 different latitudes on each plate would serve to eliminate the systematic errors in the mean. Absolute values, within the limits of the accidental errors, would thus be determined for d, and the results of the measures made by different observers and for different lines should agree very closely. I hope to test the method in the near future and eliminate the errors now present in our work.

Briefly the more important results of the present investigation are:

(1) A method is described for determining the presence and the nature of the errors in the measurements of spectral line displacements.

(2) There are systematic personal errors in the measurements of spectral line positions and displacements.

(3) The errors of measurement, both accidental and systematic, depend on the configuration measured, that is, on the grouping of the several lines in the field of the measuring microscope, and on the characters of these lines.

(4) The effect on the measurements of different observers, of the configuration employed in the present investigation is in the same sense.

(5) The systematic errors discovered in the present case are sufficiently large to introduce grave errors into one's results and into their interpretation, and consequently one's measurements cannot be accepted as sufficiently accurate without the elimination of these errors. Systematic errors ranging from 0·13 km. per sec. to 0·02 km. per sec. were found in measurements such as made for the determination of the rate of the solar rotation, the value for which at the equator is a little over 2km. per sec.!

(6) Methods for the elimination of these systematic errors are described.

That the systematic errors which occurred in the measurements of the arbitrary displacements, actually occur in the measurements of rotation plates, is seen from the following comparative values of the equivalents (in kilometers per second) to the measured displacements on various plates:

Plates	L.528a	L.531a	L.531b
Plaskett	1·866	1·868	1·872
De Lury	1·851	1·851	1·959

Plate S45a

Plaskett	1·712	1·682	
Cannon	1·632		
Parker	1·624		
Harper	1·618		
De Lury	1·592	1·618	1·624

The necessity for the removal of the errors in our work is thus emphasized. I hope to carry on further work on this question of systematic errors of measurement, and to investigate such influences as intensity of the photographic plate, the magnitude of the displacements, the character of the line with particular reference to the broad lines λ 4227, and Hα; and especially to test the methods proposed above for the elimination of these errors.

I wish to thank the gentlemen who so kindly made the comparative measurements given here; and Mr. Lucas for constructing the double-slit to work so efficiently.

DOMINION OBSERVATORY,
OTTAWA, CANADA,
December, 1911.

MARS: THE PLANET OF MYSTERY*

By C. A. Chant

THERE is perennial interest in the planet Mars. The mind of man has long speculated on the possibility of the existence, in the universe, of other worlds inhabited by intelligent beings; and with the development of astronomical knowledge,—especially since it has been shown that the earth is but one of a series of planets revolving about the sun, and further, that the numerous fixed stars are suns like our own,—our interest in other worlds has grown in intensity.

As we examine the different planets of our system, Mercury, Venus, Mars, Jupiter, Saturn, Uranus and Neptune, we soon conclude that the most likely places to look for evidence on the question are those planets nearest us,—Venus on one side and Mars on the other.

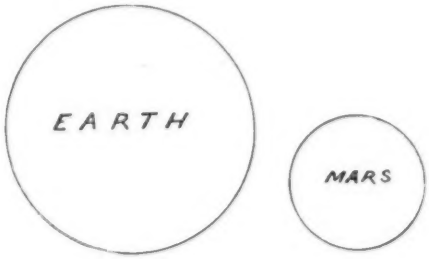


FIGURE 1.

Relative sizes of the Earth and Mars.

Now Venus is a very difficult body to study. It is almost a duplicate to the earth as regards size and density, but as its position in the sky is never far from the sun and as it is always

* Reprinted, with slight alterations, from *The Westminster*, (Toronto) for October, 1911.

enveloped in clouds, little or no detail can be detected on its surface. Close study has led to the belief that it always presents the same face to the sun (just as the moon presents the same face to the earth), and thus one-half of the body is exposed to intense heat and the other to intense cold. If such is the case, Venus is not a suitable abode for intelligent beings in anywise like ourselves.

On the other hand much interesting information has been learned about Mars. Even a small telescope will show markings on the planet, while larger instruments, especially when mounted in a locality where the air is clear and steady, exhibit many striking details. Numerous and prolonged studies of Mars have given us a mass of interesting observations, the interpretation of which has led to many diverging views as to the condition of its surface.

I. Size, Distance, Etc., of Mars

The diameter of Mars is 4,230 miles, while that of the earth is 7,918 miles; or the former is 53 per cent. of the latter. From this we find that its volume is only one-seventh, and as we know that its density is seven-tenths, we deduce the fact that the mass of Mars is one-ninth that of the earth. In the earth there is enough material to make nine planets like Mars.

The force of gravity on Mars is only 38 per cent. of that on the earth. A body which weighs 100 pounds on the earth would weigh only 38 on Mars.

The distance of Mars from the sun varies from 135 to 148 millions of miles, the mean distance being 141½ millions. In the case of the earth, its distance varies from 91½ to 94½ the mean being 93 millions. It is understood, of course, that the paths of both Mars and the earth are ellipses with the sun in one focus. The earth is in perihelion, *i. e.*, nearest the sun, about January 1, and in ahpelion, *i. e.*, farthest from the sun, about July 1. If, on the 25 of August, a line be drawn from the sun to the earth and then produced, it will cut the orbit of Mars at its perihelion, and if a line be drawn to the earth on the 20th of

February and then produced, it will cut the orbit of Mars in its aphelion (Figure 2). (This assumes that the orbits of the earth and Mars are in the same plane).

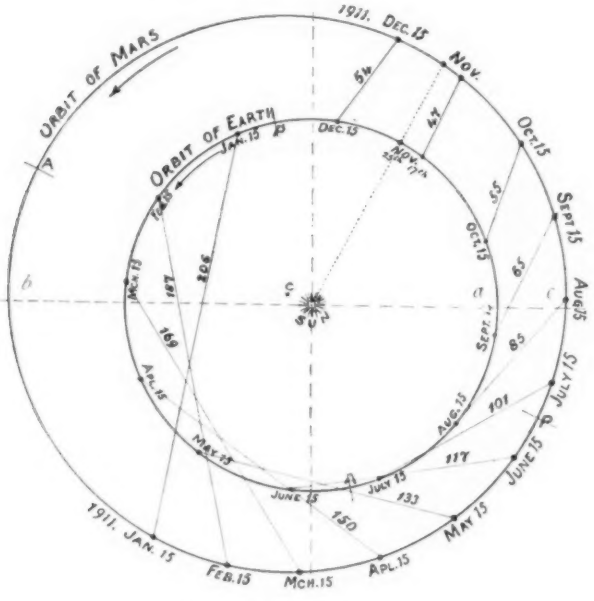


FIGURE 2.

Relative sizes of the orbits of the Earth and Mars. P stands for Perihelion, A for Aphelion. The numbers 47, 55, 65, etc., indicate the distance in millions of miles between the Earth and Mars on the dates at the end of the lines.

In Figure 2 is shown the relative sizes of the two orbits. The inner one is that of the earth, the outer that of Mars. The earth performs a revolution in 365¼ days, while Mars requires 687 days. A moment's consideration of the diagram will show that the distance between the two bodies continually changes, and that it varies within wide limits. For instance, if the earth is at *a* while Mars is at *b*, at which time Mars is said to be "in conjunction" with the sun, the distance from the earth to Mars

is the sum of their distances from the sun, or about 234½ millions of miles; while if the earth is at *a* and Mars at *c*, at which time Mars is said to be "in opposition"—it and the sun are on opposite sides of the earth—then the distance between the two bodies is the difference of their distances from the sun, or about 48½ millions of miles.

Suppose now, we start with the earth at *a* and Mars at *c*. They both move on in the direction of the arrows, and by the time the earth has come around to *a* again (*i. e.* in one year), Mars will have gone over a little more than half of its orbit. In another year, when the earth gets around to *a* again, Mars will have more than completed its orbit, and will have got a little past *c*. It will take about 50 days more for the earth to move on and come up to Mars again. Thus from one opposition to another the interval is about 2 years 50 days or 780 days.

When near conjunction the planet appears only as bright as the Pole Star, but when in opposition it is, on the average 23 times as bright. From the diagram, however, it is seen that at some oppositions Mars is much closer to the earth than at others. Indeed, this distance may vary from 61 millions to 35 millions. When closest to the earth it is 53 times as bright as the Pole Star, and is a magnificent object.

As oppositions occur every two years it becomes only that often a prominent object in the sky, brilliant enough to attract the attention of any one who looks up at the sky at all. In 1907 the opposition took place on July 6; in 1909 on September 25; and in 1911 on November 25, though on account of the fact that the orbit of Mars is an ellipse and is inclined to that of the earth, the planet was nearest to us on November 17, at which time it was 47 millions of miles away. At that time it was a fine object, rising in early evening, coming to the meridian at midnight and setting in the morning. Even now the planet is a very fine object. This year the opposition was an average one, the favorable ones occurring every 15 or 17 years.

Another interesting feature about Mars is its moons or satellites. They were not discovered until the favorable opposi-

tion of 1877. Asaph Hall, by means of the 26-inch refracting telescope of Washington, D.C., then the largest in existence, was able to detect two minute bodies revolving about the planet. The outer one, known as Deimos, is perhaps, 10 miles in diameter and 14,600 miles from the centre of Mars. It revolves in 30 hours 18 mins. Phobos, the inner one, may be 25 miles in diameter, is at a distance of 5,800 miles and revolves in 7 hours 39 mins. Now, Mars itself, as we shall presently see, rotates on its axis in about 24 hours 40 mins. This is an extraordinary state of affairs. Our moon takes 27⅓ days to revolve about the earth, while Phobos revolves three times in a Martian day! To the people on Mars (if such there be) this moon rises in the west every night, and 5½ hours later sets in the east. The discovery of this peculiar behavior of Phobos was a veritable bomb thrown into the Laplacian nebular hypothesis regarding the evolution of our solar system, from which it has hardly yet recovered.

These satellites can be seen only with a powerful telescope. The present writer, during the summer of 1907, when there was a favorable opposition, was able to detect them with the 12-inch refractor of the Lick Observatory. With it they were extremely faint, though when viewed with the great 36-inch instrument of the same observatory they were easily seen.

II. Markings on the Planet: the Canals

One of the most important drawings of the planet ever made is reproduced in Figure 3. On November 28, 1659, at 7 p.m.,

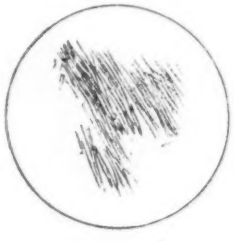


FIGURE 3.

A drawing of Mars by Huygens, 1659. It represents the Hour-Glass Sea or Syrtis Major. (From Flammarion's "La Planète Mars").

the great Huygens made the sketch, and though a very rude drawing, the part of the surface represented in it can be identified at the present time. It appears in most of the other figures. This feature is sometimes known as the Hour-glass Sea, though more commonly as Syrtis Major.

It is very interesting, after having observed the planet for some time, to give it up for a while, and then, a few hours later, to return to it again. It will then show an entirely different appearance, which will at once be recognized as being due to the rotation of Mars upon its axis. By observing on successive evenings, Huygens found that the planet rotated in about 24 hours. Later on, however, he came to doubt his results, and the honor of the discovery of the rotation period is usually given to Cassini, who in 1666 definitely determined that the planet rotated in 24 hours 40 min. Now from the time Huygens saw Syrtis Majoris precisely at the centre of the disc until we see it there again, we are sure that the planet has rotated an exact number of times, and having found this number by means of its approximate value, we can then determine the time of a rotation with great accuracy. It is 24h 37m 22·7s.

Viewed through a powerful telescope, the planet's disc, as a whole, is ruddy or orange-colored. Around the edge it is especially bright. At the central portion of the planet greenish and purplish patches, most of them not very well defined, are to be seen.

Numerous astronomers, both amateurs and professionals, from the time of Huygens onward, have attempted to draw the surface as it appeared to them. The results are very interesting and agree well as to the main features, but in regard to the finer details there is much discordance, and it unfortunately happens that upon these faint markings many of the arguments as to the conditions existing on the planet and the presence there of intelligent inhabitants are based.

A number of these drawings are reproduced herewith, taken for the most part from Flammarion's great work entitled "La Planète Mars." In Figure 4 is a sketch by Schroeter, a very

FIGURE 4.

Drawing of Mars by Schroeter, Sept. 10, 1798. This shows Syrtis Major plainly.

active and competent astronomer of Lilienthal, Germany, made in 1798. It shows the same Syrtis Major which appears in Huygens' drawing, and also the south polar cap. In Figure 5 are two sketches made in 1832 by Beer and Maedler, two very

FIGURE 5.

Drawings by Beer and Maedler, 1832. The right hand one was made about three hours after the other.

able German astronomers. Here we have the same familiar Syrtis Major, the second sketch having been made about three hours after the other and showing the planet's rotation.

With improvements in the telescope came better drawings of the planet. In Figure 6 is shown a drawing by the English astronomer de la Rue. Both polar caps and Syrtis Major are very prominent. In Figure 7 is a sketch by Kaiser, of Leydon, November 22, 1864, 8 p.m., which may be compared with Figure 8, by the famous English amateur, Rev. W. R. Dawes, made on November 26, 1864, at 11.36 p.m.

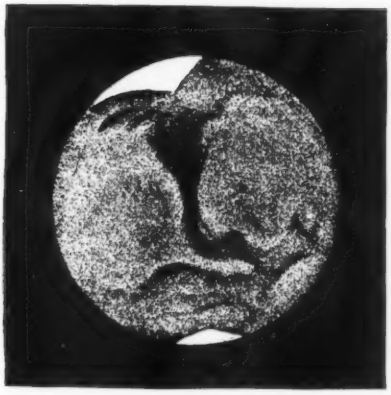


FIGURE 6.

Drawn by Warren de la Rue, April 20, 1856, 9.40 p.m.
Note the two polar-caps and Syrtis Major.

FIGURE 7.

By Kaiser of Leyden, November 22, 1864, 10.45 p.m.

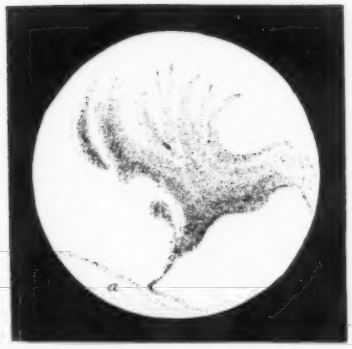


FIGURE 8.

By Dawes, November 20, 1864, 11·36 p.m.

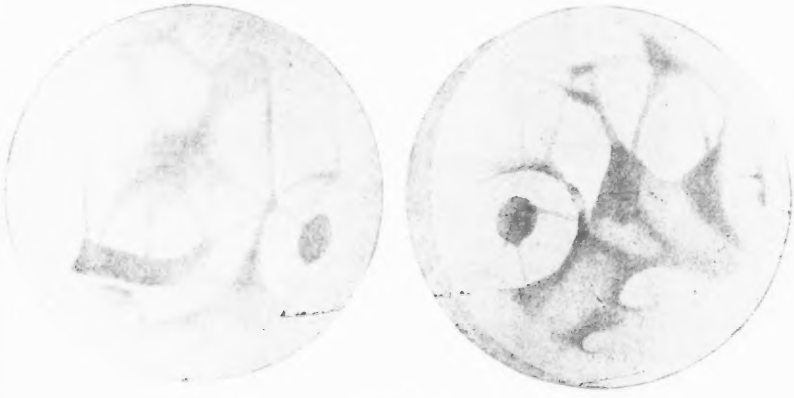


FIGURE 9.

December 26, 4.47 a.m. November 11, 5 35 a.m.

Drawings by Schiaparelli in 1879 showing canals.

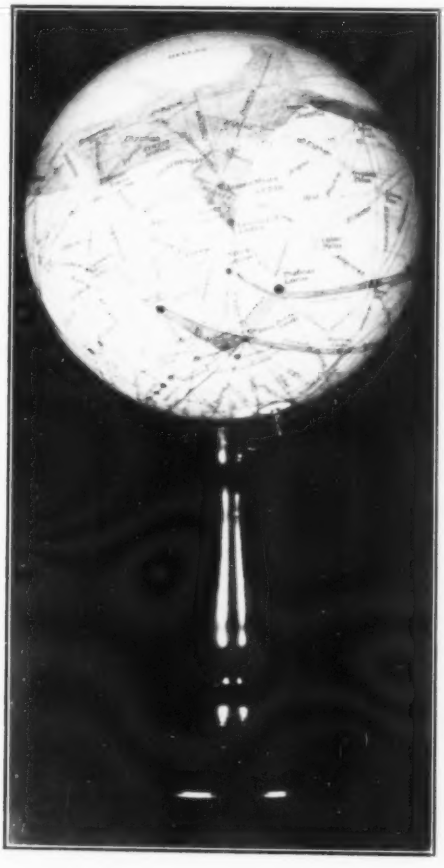


FIGURE 11.

A globe of Mars by Lowell, 1905.

FIGURE 12.

Drawn by Keeler, May 29, 1894, 11.45 p.m., with the 36-inch refractor of the Lick Observatory.

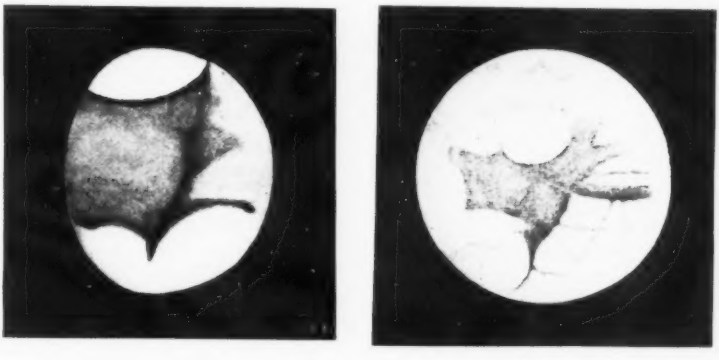


FIGURE 13.

Two views of Mars showing seasonal development. The smaller was made near the spring equinox of Mars, the larger during the summer on Mars. (From Lowell's "Mars," published 1896).

In these drawings may be seen the white polar caps, the large dark markings and also some finer streaks over the disc. Note also the bright illumination around the edge of the disc. But in 1877 and 1879, Schiaparelli, a distinguished astronomer of Milan, announced the discovery of a great number of fine straight lines or "canals" crossing the ruddy part of the disc. In Figure 9 are shown two sketches by him made in 1879. This announcement was startling enough, but in 1881 he added to it by stating that he had observed that some of these canals became double at times. Figure 10 shows a drawing by Schiaparelli, made in 1890, exhibiting this extraordinary feature.

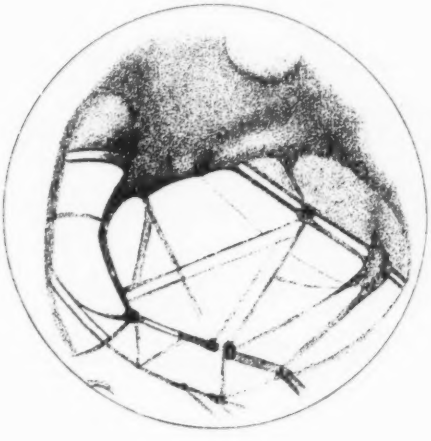


FIGURE 10.

Drawing by Schiaparelli, June 20, 1890, showing double canals.

Schiaparelli's observations have been confirmed and added to by leading astronomers, both in Europe and America. Of the latter Percival Lowell is the most famous. Dr. Lowell is a member of a distinguished Boston family, his brother being now president of Harvard University. Possessing ample means, he is using it in a splendid work. He has equipped and maintains a

first-class observatory, which is devoted chiefly to planetary observations. It is located at Flagstaff, Arizona, where the atmosphere is especially clear and steady. For seventeen years the work has been carried on, and a great amount of matter, chiefly on Mars, has been published. Dr. Lowell has also published several books, all written in an attractive style and sumptuously illustrated. They have done much to stimulate interest in the study of the planet. Figure 11 shows a globe of Mars constructed by Lowell in 1905.

Lowell and his assistants have not only observed the canals discovered by Schiaparelli, but have multiplied the number several times. Indeed, no fewer than 690 are reported to have been observed and mapped! Many of them are long (some 3,000 miles) and straight, and strongly suggest an artificial origin.

Unfortunately, however, several other astronomers, equally experienced and possessing as good instruments, cannot see these fine markings. They are just on the limit of visibility, much like a telegraph wire at the distance of a quarter of a mile. Various attempts have been made to show that the canals are simply due to optical illusion, but the positive evidence of their existence can hardly be overthrown by negative results. It is much to be regretted, however, that all cannot see them. Excellent photographs of the planet have been taken, but they are necessarily on a very small scale, and though showing the chief markings and even some canals, they fail entirely in the finer ones. In Figure 12 is a drawing by the eminent astronomer Keeler, with the 36-inch Lick telescope.

The white polar caps act as if they are sheets of snow and ice, disappearing as the summer comes on. It has been contended that they cannot be such, on account of the low temperature on the planet, but this objection has been brushed aside by Flammarion and Lowell, who take these features to be just what they appear to be. It is generally agreed that the greenish patches are probably due to vegetation springing up as the water becomes diffused over the surface and as the summer advances. According to this view, the canals are made visible by the vege-

tation fringing their banks. In Figure 13 are two views of the planet showing seasonal development. The smaller one shows the appearance of Syrtis Major in June, 1894, spring on Mars; the larger shows it in October, 1894, at which time it was summer in the southern hemisphere, which is shown in the picture.

The orange-colored portions of the disc are probably deserts. They cover more than one-half of the surface, and though the surface of Mars is remarkably flat, yet any system to irrigate these plains would have to be on a colossal scale. Lowell argues that the canals are actual waterways constructed for this purpose, and he certainly presents his arguments in an interesting and masterly way. We know, from various lines of reasoning, that the supplies of air and water on Mars are very scanty, and as these are the two essentials to life as we understand it, the problem before the Martians of maintaining an existence appears to us a very serious and difficult one. But Dr. Lowell is confident that, just as Mars as a world has proceeded farther in its course of development than has our earth, so also have the race of Martians developed beyond ourselves, sufficient indeed to overcome all their hard circumstances.

That ours is the only planet in the universe on which intelligent life exists seems, on the face of it, improbable; but the extraordinary difficulty in obtaining evidence on the question renders it pretty certain that no definite answer to it will be found for many years to come.

MEETINGS OF THE SOCIETY.

FINANCIAL STATEMENT
THE ROYAL ASTRONOMICAL SOCIETY OF CANADA.

1910	RECEIPTS, 1910		
Jan. 1	Cash in Imperial Bank	2146.36	
	Grant from University Library (for exchanges)	100.00	
	Grant from Ontario Legislature	600.00	
	Grant from Dominion Government	2000.00	
	Grant from Corporation of Toronto City	100.00	
	Fees from Members	602.54	
	Interest on Deposits and Bond	99.81	
			$5648.71

1910	DISBURSEMENTS, 1910.		
Dec. 31	Publication of JOURNAL	1938.68	
	Public Meetings	91.25	
	Library—for books and binding	147.60	
	Exchanges on cheques	5.21	
	Stationery and Stamps	81.15	
	Slides for Lanterns	43.00	
	Salaries	305.83	
	Rent of Rooms	200.00	
	Grant to Peterboro Centre	120.00	
	Grant to Hamilton Centre	150.00	
	Grant to Ottawa Centre	100.00	
	Dr. Chant's expenses to Solar Conference	150.00	
	Sundry Accounts	23.60	
	Balance in Imperial Bank	2253.74	
	Balance Reserve Fund	38.65	
			$5648.71

CHAS. P. SPARLING,
General Treasurer.

Examined and found correct,
(Signed) ROBERT TYSON.
Toronto, January 1, 1911.

AT TORONTO.

Tuesday, October 10.—The Librarian's report of books and periodicals received since the last meeting was presented.

Mr. J. R. Collins gave the predictions for the next two weeks, also observations made by members during the summer.

The lecture of the evening was given by the President, Professor A .T. DeLury, on "Celestial Measurements." The lecturer indicated that such measurements are largely approximations, reaching higher and higher degrees of accuracy with the improvement of methods and instruments and the increased skill of observers. He showed how the method of diagrams was applied to various problems, *e. g.*, to get the relative positions of the earth, Venus and the sun. He also described briefly but lucidly the following measurements:

(*a*) The mass of bodies: *e. g.*, the earth and the moon.

(*b*) The amount of variation from the spherical shape in the surface of the earth.

(*c*) The distance of the moon from the earth.

(*d*) The distance of the earth from the sun, using transits of Venus.

(*e*) The diameter of the moon.

Tuesday, October 24.—Mr. Alfred Apps, of Brantford, was elected a member of the Society.

Mr. Elvins and others spoke of comets visible at the present time or recently.

Two queries were presented. One by Mr. Elvins was in relation to the cause of the precession of the equinoxes. At the request of the President, Mr. Paterson undertook to discuss the question at the next meeting of the Society. The other query was presented by Mr. Sharpe, on the rotation on the moon. Messrs. Musson, Paterson and Sharpe, the President, and Mr. Tyson, took part in the discussion.

The President gave as the lecture of the evening a continuation of the paper of the last meeting on "Celestial Measurements." The solar system was first considered, with the motion of the

planets about the sun and of the satellites about the planets. From this it was shown how the idea of mass is established, and how the measurement of the mass of the planets and of the sun is made. In this connection the laws of Newton and Kepler were shown to be the foundation of the method of measurement, and that its development was made from that basis.

Tuesday, November 7th.—Miss M. J. Blake, of Kelowna, British Columbia, was elected a member of the Society.

In reference to the question asked by Mr. Elvins at the last meeting, Mr. J. A. Paterson, K.C., discussed the subject of the "Precession of the Equinoxes." Mr Paterson described the process by which the earth acquired its present form, with its "bulge" at the Equator. He then explained the method of indicating the position of the stars, and went on to describe how longitude changes during the year. In conclusion, he presented the theory of the cause of the precession and nutation of the equinoxes.

Dr. Chant gave the lecture of the evening, his subject being "The Coming Opposition of Mars." The lecturer began by giving an outline of past observations on the planet. By the aid of diagrams he demonstrated the phenomena of conjunction and opposition of Mars, and the times at which these take place, also the occasions when conditions were most favorable for observation at times of opposition. Next, he showed by means of lantern slides the conditions and appearances which observers see on the surface of the planet; and proceeded to discuss the evidence for the existence of water vapor and other suitable conditions for supporting life on Mars.

Tuesday, November 21.— Mr. K. G. Fletcher, B.A., 532 Huron St., Toronto, was elected to membership in the Society.

The secretary stated the predictions for the coming two weeks. He also submitted a written statement of observations of meteors by Mr. W. P. Byrch, as follows:

"On Tuesday, August 29th, 1911, at 8.25 p.m., while on board the steamer Turbinia, then proceeding to her moorings at the Yonge street wharf on her last trip of the season, I observed

a large meteor in the south-east, passing in a slanting direction to the south-west. In its course it dived into a heavy white cloud apparently half way between us and Niagara. For three or four seconds it was invisible; then a bright light appeared in the under part of the cloud, and out of this the meteor again appeared, apparently dropping into the lake without any noise. This meteor was about one-eighth the size of full moon. It had a yellowish green center (Chlorine gas?), with a bright white envelope like the incipient tail of a comet.

"On October 4th, 1911, about nine o'clock p.m., I observed a bright blue meteor moving from south-east to south-west, where it disappeared without noise.

"About the 12th of October I observed a meteor from Andromeda cross southward and disappear about south-west. This was not at all a bright object, having a patchy burnt out appearance."

Mr. John A. Paterson, K.C., M.A., gave the lecture of the evening on "The Apex of the Sun's Way." After explaining the title of his lecture, Mr. Paterson gave an historical outline of the astronomical development which had led to our present knowledge of the motions of the earth, the solar system, and other stellar systems. He described the isolated position of the solar system in space, showing clearly how great was our distance from the nearest stars, and went on to present a beautiful picture of the grandeur of position and conditions of the solar system. Next he outlined the advancements of recent years in the method of detecting stellar motions and ascertaining the relations of the solar system to the stars; then proceeded to show the bearing of these advancements upon the determination of the path of the solar system in space. He next dealt with the principle of "residual phenomena" as used in suggesting new physical causes, and referred to Sir William Herschel's work on the "Sun's Way" by this method.

A discussion of the subject followed, which was participated in by Messrs. Cuthbert, Gray, Mason, and others.

Tuesday, December 5th.— The Recorder read a report from Council, stating the names of the persons proposed for officers and council for 1912, in accordance with Article Six of the Constitution. These proposals were unanimously adopted at the Council meeting of December 1st, 1911, and are as follows:

Honorary President—Dr. W. F. King, C.M.G., L.L.D., Ottawa.

President—Professor L. B. Stewart, Toronto.

First Vice-President—J. S. Plaskett, B.A., Ottawa.

Second Vice-President—A. D. Watson, M.D., Toronto.

Secretary—J. R. Collins, Toronto.

Treasurer—Chas. P. Sparling, Toronto.

Recorder—Lachlan Gilchrist, M.A., Toronto.

Librarian—Dr. W. M. Wunder, Toronto.

Curator—R. S. Duncan, Toronto.

Council—G. Parry Jenkins, F.R.A.S., Hamilton; Rev. I. J. Kavanagh, M.A., D. Sc., Montreal; Rev. Dr. Marsh, F.R.A.S., Peterborough; A. F. Miller, Toronto; Joseph Pope, C.M.G., Ottawa, R. M. Stewart, M.A., Ottawa.

Miss Estelle Foy, 9 Dundonald Street, Toronto, was elected a member of the Society.

The predictions, and Librarian's report were presented.

Under the head of observations, Mr. R. F. Stupart reported that the sun had been almost free of spots for some time past.

Mr. R. F. Stupart, Director of the Meteorological Service of Canada, then gave the paper of the evening on the "History of the Development of Meteorology in Canada." The paper was illustrated by lantern slides, and was greatly appreciated. It will appear in the Society's JOURNAL.

Answering a question which had been put in reference to the two small satellites of Mars, as to whether there was any probability of one or other falling gradually to the surface of the planet, Dr. Chant said there were no indications whatever of such a thing happening. He cited from the *American Ephemeris and Nautical Almanac* to show that these satellites maintained regular orbits. A brief discussion followed.

Tuesday, December 19th.—A communication was read from the Winnipeg Centre, saying that a speaker would be acceptable there for some of their meetings.

From Barcelona, Spain, a circular had been received in reference to an organization for lunar studies and meetings connected therewith.

Mr. Ernest A. Hodgson, Toronto, was elected to membership.

Mr. J. R. Collins mentioned a query that might be answered at the next meeting: namely, the reason why daylight at this season lengthens sooner in the evenings than in the mornings: that is, why the sun begins to set later and later in the latter part of December, but continues to rise later, and does not begin to rise earlier until about the first week in January.

Professor Louis B. Stewart delivered the paper of the evening on "The Figure of the Earth."

The lecturer began by stating some of the earliest recorded conceptions concerning the shape of our planet. Aristotle taught that the earth was spherical; also Posidonius about two hundred years later. Ptolemy in his Geography stated that the length of a degree was about fifty-eight miles.

In the year 814 A.D. an Arabian caliph attempted to solve the problem of the length of a degree by sending one party north and another south, to travel until the altitude of the pole changed one degree. About seventy-one miles was the result.

After that, nothing is known to have been done in the matter until the year 1525, when an arc of the meridian was measured by counting the number of revolutions of a carriage wheel to determine the distance between two stations one degree apart and making astronomical observations. The result came very near the truth.

In 1515 Snellius first employed the method of triangulation, using as his starting point a base-line near Leyden.

The first attempt at measuring a degree in England was made by Norwood in 1635. He measured from London to York, and got close to the truth.

Picard in 1669, was the first to use telescopic sights on angle-

measuring instruments. Triangulation was carried out from near Paris to near Amiens. This work was notable as furnishing Newton with data from which he was able to establish proof of the law of Universal Gravitation ; and it probably encouraged him to publish the *Principia*.

Up to this time the earth was supposed to be a sphere ; but discoveries of Richer in 1672, relating to the variation in the pendulum swing, turned the attention of astronomers to the idea that the actual shape of the earth might not be so.

Picard's original triangulation was gradually extended, and much attention was given to obtaining the measurement of a meridian arc. Expeditions were sent to various parts th the earth; two notable ones being in 1736, to Lapland and Peru respectively. The measurements of those two expeditions, and the measurement in France, showed conclusively that the form of the earth was an oblate spheroid.

The next point was to determine the dimensions of the generating ellipse of the spheroid, and much scientific energy was devoted to this problem. The speaker described the various measurements made for this purpose ; referred to the advantage gained by the invention of the theodolite ; and described the origin of the metre as a unit of length. Nine arcs were measured during the 18th century.

An outline sketch of the geodetic work of the 19th century followed, showing that trigonometric surveys were carried on vigorously in many countries, and great improvements made in instruments and methods.

The speaker next dealt with the state of the earth's interior called isostasy, shown to exist at and below a depth of about 76 miles beneath the surface.

Triangulation in the United States of recent years had resulted in the longest line that was ever measured in triangulation. The length of that line is 183 miles.

Other methods than direct measuring were used, one being the determination of the force of gravity at various points on the

earth's surface. "Geoid" is the name now applied to the figure of the earth.

The lecture concluded with an interesting exhibition of lantern slides.

Some conversation followed a question put by Mr. Maybee about the exploratory and scientific work done by Professor Stewart in Labrador.

The gold medal, for presentation by the Society to the student in the University of Toronto attaining the highest distinction in astronomical studies this year, was on the table, and was inspected by the members.

L. G.

At Ottawa

October 12, 3 p.m., in the Dominion Observatory.— Messrs G. H. Herriot and J. F. Freddette, both of the Topographical Surveys Branch, Department of Interior, Ottawa, were elected members.

The paper of the afternoon was one by Mr. R. J. McDiarmid, M.Sc., on "Methods of the Allegheny Observatory." Mr. McDiarmid first traced the history of the Observatory from a beginning in 1858 as a "Telescopic Society." The names of Brashear and Langley were mentioned as associated with its development. The first observatory was near the Brashear optical works where a 13-inch refractor was installed. Subsequently, owing to the smoky atmosphere, caused by the steel industry, the observatory was removed to the northern extremity of the city to an altitude of 1200 feet. New telescopes were installed, one of which was a 30-inch reflector designed for photographic work. Mr. McDiarmid described this instrument in detail and showed how it was used in spectroscopic work. He then outlined the methods used for measuring and reducing plates taken in the work and pointed out some advantages in the method.

In the discussion which followed Mr. Plaskett briefly outlined the several methods used in measuring the lines on a photo-

graphic plate and compared them with that in use at the Dominion Observatory.

October 26.— Mr. F. Connor, B.Sc., Geological Survey, Ottawa, was elected a member of the Society.

Mr. J. S. Plaskett, the President of the Ottawa Centre, was in the chair, and after a few words of welcome to the audience and a short statement of the aims of the Society and the course of public lectures to be given during the coming months, introduced the speaker of the evening Mr. F. A. McDiarmid, B.A.

Mr. McDiarmid's subject "Distances of the Stars" was treated by him in a popular manner and was well illustrated by diagrams and drawings projected on the screen. He first treated briefly of attempts made by the early astronomers to measure distances to the stars, the most noteworthy being the attempt to measure the diameter of a star and so deduce its distance, on the assumption that the decrease in diameter is due to distance alone. After defining parallax he showed how the surveyor or engineer obtained the distance to an inaccessible mountain peak. From this illustration he explained how the distances to the moon and the sun were obtained. The distances to the fixed stars were obtained by their parallax. This quantity was exceedingly small and required the most precise methods for measurement. In addition to the possibility of measuring the parallax of a star, due to the earth's motion about the sun, the greater parallax due to the motion of the whole solar system after years' duration could be measured. The parallax of about 200 stars has been determined and results show that some of the nearer stars are quite small while some of those farther away are large. One of the surprising later results of investigation show that the types of stars as classified by their spectra appear to vary with their distance from us. Mr. McDiarmid's lecture closed with a contemplation of the great problems of the universe and a hope that future generations would help to solve them.

At the close of the lecture it was found that the clouds rendered it impossible for the audience to observe with the telescope. Accordingly after the formal adjournment of the meeting a series

of views was shown by Mr. Plaskett, many of them bearing closely on the lecture.

November 9, 3 p.m.— Dr. Klotz delivered the address of the afternoon on "More Crumbs from Europe." These "Crumbs" were gleaned from his attendance at the International Seismological Conference held at Manchester last summer, and from a subsequent visit to earthquake stations and scientific institutions on the continent as far east as Budapest, and were in keeping with his address on a former occasion entitled "Scientific Crumbs from Europe."

The talk by Dr. Klotz was crowded with the most interesting information not only about seismology and astronomy but also about the places he visited. At Manchester he met with many scientists of note among whom were Sir George Darwin, Professors Horace Lamb, Milne and Schuster, Dr. W. N. Shaw, Professor Love, Prince Galitzin, of Russia, and others. Dr. Klotz then gave a statement of the principal papers read at the Conference with a brief synopsis of each. He himself had presented two papers. One of the important resolutions of the conference related to the deformations of the earth under the attractive influence of the moon, with the recommendation of establishing four new stations one in central Southern Africa, one in central Siberia, one in central North America, the last three to be removed from oceanic tides. It is probable that the last station will be at Winnipeg.

Dr. Klotz spoke of his visit to the new magnetic Observatory at Eskdalemuir and to Jugenheim where he listened to clock signals coming several hundred miles through the air from the wireless station at Norddeich. He spoke of his visit to the central station at Strassburg, to the meteorological and astronomical observatories at Vienna, and briefly described Baron Eötvös's torsion balance seen at Budapest by means of which differential gravity to the order of 10^{-9} C.G.S. units can be measured. At Prague he handled two of Tycho Brahe's instruments which he described. The activities at Potsdam in meteorology and terrestrial magnetism also received brief reference. The time service

for shipping and public use at Hamburg also received due attention as well as the work carried on at the geophysical institute at Göttingen.

Time forbade describing his visit to the efficient observatory at Wilhelmshafen, the splendid imperial wireless station at Norddeich, nor of his visit to Bidston Observatory and the wireless station at Seaforth near Liverpool.

In closing Dr. Klotz paid a tribute to the kindness and generosity of Dr. King in equipping the observatory so well, and pointed out that it remained for the staff to do their share to build up the name and honor of the institution.

November 23, 8 p.m.— Mr. R. C. McCully, M.A., Dominion Observatory, was elected a member of the Society.

Mr. R. M. Stewart, M.A., then read a paper on "Motions of the Stars."

Mr. Stewart first spoke of the minuteness of these motions when measured in seconds of arc, but showed that such minuteness was only apparent on account of the immense distances of the moving bodies. When calculated in miles per second the speeds are astonishing. Owing to these motions the face of the heavens changes its appearance slowly but surely, so that it would not be recognized after a lapse of, say, 20,000 years. The motions were in all directions and subject evidently to only one law, namely, they were all rectilinear.

Mr. Stewart then spoke of stars whose motions were irregular, due to the presence of a second body which though unseen in some cases was shown to exist by the evidence of the spectroscope; and discussed the different phenomena of such systems, such as the length of their periods of revolution and the variability of their light.

He then spoke of clusters or streams of stars moving in parallel lines. The number of such groups was too great to account for the motion being a thing of chance. These stars probably got their motions from some common source and at the same time. As a rule they were all stars of new spectral type

and we may expect that gravitation will finally break up their common motion.

Mr. Stewart then discussed at some length the motion of the stars as caused by the sun's motion through space and also the later theory of two great streams or drifts of stars.

He finally pointed out the great importance of the recent discovery that the motions of stars vary according to their spectral type, the older stars moving faster than the newer ones.

After the lecture Dr. Brashear, the famous instrument maker, gave an interesting and reminiscent talk in which he very clearly showed the progress of science during his lifetime.

December 7, 3 p.m.— Mr. R. M. Stewart presiding.

Mr. J. S. Plaskett gave the afternoon address entitled "The Solar Rotation."

Mr. Plaskett first explained that he would discuss the problem of the sun's rotation as solved by one method only, viz.: — the measurement of the displacement of lines from spectra of opposite limbs of the sun. He gave a brief historical sketch of this method which began as far back as 1876, when the displacement was measured visually by Young. The latest measures were made by mean of photography and of these the work of Adams, of Mount Wilson, 1906-7 and 1908 ranked high in accuracy both as regards the measurements of the plates and the values obtained therefrom.

Mr. Plaskett then briefly explained the apparatus necessary for photographing the spectra from opposite limbs. A large image of the sun was projected by a cœlostat telescope on the slit of the spectrograph. After passing through the slit the light was incident on a lens whose focus was at the slit. The emerging pencil of parallel rays was broken into a spectrum by a diffraction grating and sent back nearly along its original course and brought to a sharp focus by the same lens on a photographic place just below the slit. A special device for obtaining light from opposite limbs of the sun at the same time was explained by means of a drawing.

The method of using this apparatus and the precautions necessary for accurate work were then taken up. It required a knowledge of the position of the sun's axis at the time of observation, a sharp image of the sun guided centrally with respect to the slit and precautions against systematic errors for good work. Some of the precautions against systematic errors were a sharply focussed plate, a uniformly illuminated grating, good solar definition and a sky clear from haze.

Having outlined the method Mr. Plaskett gave the results of his measurements of various plates taken by himself and Dr. DeLury. He also discussed the several corrections necessary to such measures before the final result could be obtained.

Mr. Plaskett then discussed the results generally and with a view of ascertaining (1) The law of retardation as we approach the pole, (2) The constancy of the revolution, (3) Whether different elements show different rates of rotation. The results of Mr. Plaskett gave substantially the same law of rotation as that obtained by Adams. The second question could not yet be discussed as sufficient information was not available. His answer to the third question was that so far as his measurements show, there seems to be nothing to warrant the conclusion of Adams that different elements have different rates of rotation. Mr. Plaskett believed that Adams results might be due to small systematic or personal errors.

C. E.

At Hamilton

November 7.— Notwithstanding the very unpleasant weather there was a goodly number out to hear Rev. Dr. Marsh, of Peterborough, give a lecture on "Our Nearest Neighbor."

Dr. Marsh described the appearance of our satellite exhibiting many views showing the roughness of the surface, the craters, mountains, mountain ranges, valleys, etc.

The various theories of the moon's origin were discussed, its various movements and its effect upon the earth were discussed and explained.

November 21.— Dr. C. A. Chant gave a very interesting address on "The Planet Mars and the Present Opposition."

He stated that more interest was taken in Mars than in almost any other celestial body and this for two reasons; firstly, it was Tycho Brahe's observations of this planet which enabled Kepler to formulate his three great laws and, hence eventually leading up to the enunciation of Newton's law of gravitation; and secondly, on account of the speculation concerning the habitability of Mars.

Having first rapidly looked at the likelihood of there being life on any of the other planets. Dr. Chant said he would treat his subject under three heads, viz.:

1 A general statement as to size, motions, distances, etc.

2 Drawings made at various times showing the surface markings.

3 An account of attempts to obtain evidences of the presence of water vapor and oxygen.

Many slides were shown giving a splendid idea of the advances in seeing powers of telescopes from the first dimly seen markings up to the wonderful series of lines vouched for by Lowell.

Spectrographs were then shown and explained, the absorption bands being pointed out with account of the discordant results arrived at by such observers as Slipher and Campbell.

T. H. W.

At Peterborough

November 7.— The opening meeting of the R. A. S. C., Peterboro' Centre, was held in the lecture room of the Collegiate Institute. The President, Mr. H. O. Fisk, in the chair. The attendance was large.

Mr. Henry Carveth gave some interesting notes on his observations during the summer months with the Toronto Telescope. Mr. Richardson and several of the Brighton members reported observations made with the Stratton Telescope.

The lecture of the evening was by Dr. Marsh, and was the

first of a course of lectures on "The Moon." In addition to giving the various theories of its formation, he spoke of its orbit, distance, effect on the tides and the earth's crust, etc.

November 21.—The meeting was fairly well attended, the President in the chair. Owing to bad weather only a few observations had been made since last month.

The lecture, which was profusely illustrated, was by Dr. Marsh and was entitled "How the Surface of the Moon became Rough."

December 19.—The Annual Meeting was held in the Collegiate Institute, the President, Mr. H. O. Fisk in the chair.

The reports submitted were most encouraging. Ten lectures were given during the year, all of which were well attended. The membership stands at 45.

The following officers were elected for 1912:—

President—H. O. Fisk, C.E.

Vice-President—T. A. S. Hay, C.E.

Secretary-Treasurer—Rev. D. B. Marsh, Sc.D., F.R.A.S

Councillors—A. J. Seger, Duncan Walker, B.A.; Thomas Elliott, Henry Carveth, S. J. Keyes, B.A.; A. J. Johnston, Phm.B.; D. E. Easson, B.A.Sc.

Curator—H. O. Fisk, C.E.

Librarian—T. A. S. Hay, C.E.

Auditor—Frank Adams.

After the transaction of business, a lecture on "The Planet Saturn" was given by Dr. Marsh, illustrated by a fine set of slides belonging to the Society.

D. B. M.

At Regina

Programme for 1911-12.

October 20—"The October Constellations." (Illustrated by lantern slides).—Mr. Hector Lang, B.A., President.

November 17—"Galileo and His Contemporaries." (Illustrated). Mr. Jas. Duff, M.A.

December 15—"The Age of the Earth." (Exhibition of Fossils).—Mr. Norman MacMurchy, B.A.

January 5—Subject to be chosen.—Prof. G. H. Ling, M.A., Ph.D., University of Saskatchewan.

January 19—"The Eye as an Optical Instrument." (Illustrated).—Mr. H. S. McClung, (Optometrist).

February 16—"Ancient Astronomy." (Illustrated).—Mr. George Simpson.

March 1—"The Pendulum." (Illustrated by experiments).—Magistrate Trant.

March 15—"The Poetic Side of Astronomy."—A. H. de Tremaudan.

April 19—"The Laws of Light." (Illustrated by experiments).—Mr. W. G. Scrimgeour, M.A.

May 17—"The Solar Spectrum." (Illustrated by experiments).—Mr. A. J. Pyke, B.A.

The above lectures are open to the general public. In addition to this more or less popular astronomy, the members of the Society hope to meet once each month and spend the evening in a practical and experimental study of the science. In this way we hope to spend part of our time studying away together and part of it explaining to others what we have learned.

October 20—A large number of people were present to hear a very able and interesting address given by Mr. Hector Lang, B.A., President of the Regina Centre, who took for his subject "The Constellation of the October Sky."

Mr. Norman MacMurchy, B.A., occupied the chair, and as the general public was invited to the meeting it was decided to postpone the general business until the next meeting. After a few words of welcome in which Mr. MacMurchy outlined the aims of the Society, he called on Mr. Lang to give the address of the evening.

The President introduced his subject "The October Sky"

under the following topics :—Why we have a different sky for the various months of the year ; the meaning of the signs of the Zodiac and the chief ecliptical sign for October (Aquarius). He then gave some very interesting information about the way in which the ancients named the constellation and showed how the names so peculiarly chosen have remained to this day.

Afterwards considerable time was devoted to locating and describing the various astronomical phenomena peculiar to the October sky.

The lecture was splendidly illustrated by lantern slides loaned to the Society by Dr. C. A. Chant, M.A., of the University of Toronto.

The lecture was full of interest and the large audience speaks well for the future of the Society in Regina.

November 17.—The subject for this meeting was "Galileo and His Contemporaries," and it was ably discussed by Mr. James Duff, M.A. THE JOURNAL hopes to publish the paper in a future issue.

December 15.—Mr. Norman MacMurchy addressed the meeting on "The Age of the Earth," or, perhaps, more accurately, "The History of the Earth."

The attendance was very good and the lecture was presented in a very able and interesting manner making the meeting one of the most profitable of the year so far.

The lecturer divided his subject into two parts

(1) Astronomical : dealing with the various theories as to the origin of the earth, the nebular theory and the planetesmal theory.

(2) Geological : treating in turn the general formation of the earth, the peculiarities of plant and animal life during the several periods of the earth's history.

A goodly collections of rocks and fossils greatly aided the audience in appreciating that the rock formations were the pages from which we learn of the earth's remarkable history, and they were of great value to the lecturer while discussing the formation

of the earth, and while dealing with the various changes and remarkable development in animal and plant life throughout past time. The lecture was very well illustrated by an excellent series of lantern slides loaned for the occasion by Dr. C. A. Chant and Dr. W. A. Parks, of the University of Toronto.

Owing to the absence of Mr. Hector Lang, the President of the Centre, Mr. Wm. Trant occupied the chair. He well voiced the sentiments of the audience when he expressed his appreciation of the very interesting and excellent paper given.

A. J. P.

At Guelph

November 9.—A meeting of the Society was addressed by Professor C. A. Chant, of Toronto, on the subject "Mars."

The lecturer showed by lantern slides the relative position of the planets to the sun and their relative sizes. He explained the term "Opposition," and showed why a better view of Mars could be obtained at some times than at others. He made mention of the moons of Mars and their times of rotation and the peculiarity of one of them in that on account of its rapid motion it rose in the west and set in east. Dr. Chant gave many views of Mars as sketched by artist astronomers, and explained the theories relating to the varying changes of light and shades on the surface of that planet.

A hearty vote of thanks was tendered by Professor Reynolds seconded by Mr. Buckingham.

December 7.—The Society was entertained by Mr. J. A. Paterson, K.C., of Toronto, on the subject "The Astronomy of Shakespeare." The lecturer stated that there are birth pangs in the intellectual world, and that the knowledge of astronomy keeps growing. Astronomy had a prominent place in the learning of the sixteenth and seventeenth centuries, but Milton and Bacon, very learned men as they were, had inaccurate conceptions of the universe.

But Shakespeare, almost a contemporary of both, with true prophetic vision, had arrived at many correct conclusions.

Mr. Paterson by many apt quotations showed how intimate Shakespeare's knowledge was of astronomical terms, and how he believed in such truths as the rotundity of the earth and gravity.

A vote of thanks, moved by Sheriff Allan and seconded by Mr. Jas. Watt was heartily applauded.

A very interesting feature of the meeting was the presentation to the Guelph Centre of the Society of a six-inch telescope by the President, Mr. H. Westoby.

A vote of thanks expressing the Society's appreciation of Mr. Westoby's generosity and interest was moved by Mr. Leadley and seconded by Mr. Asbury. The motion was put to the meeting by the lecturer of evening, Mr. Paterson, who stated that this was the largest telescope in the possession of any Centre in Canada. He considered Guelph very fortunate in having such a President.

J. T. L.

NOTES FROM THE DOMINION OBSERVATORY

A HALO.

On the evening of January 3 last, a beautiful halo surrounded the moon and lasted for several hours at Ottawa, although the writer did not see it until 11 p.m. The night was comparatively clear, only a thin veil overspread the whole sky, blotting out the smaller magnitude stars. The temperature was bracing, being $-15°$ C, or 5° above zero Fahrenheit.

The circular band about the moon, which was about at full, was complete, and distinctly showed colored fringes, the inside red and the outside blue, while between, the colors were blurred. What was of particular interest to the writer was that he noticed Betelgeuse (α Orionis) just within the red fringe, while Capella (α Aurigæ) was just on the outer edge of the blue fringe. This phenomenon gave an opportunity of finding the radius of the halo or ring, which is generally referred to as the 22° halo.

Pernter in his "Meteorologische Optik" has treated the subject of halos and allied phenomena very exhaustively. The halos are principally due to the reflection and refraction of light by ice crystals or ice-spiculæ, which are all of the hexagonal form or modifications thereof.

Pernter gives the general formula

$$\text{Sin } \frac{D_\circ + 60°}{2} = n \sin 30°,$$

where $D_\circ$ is the angle of minimum deviation for a particular wave-length, and n = coefficient of refraction for the respective wave- ength. If we take for red $n = 1{\cdot}3065$ and for violet $1{\cdot}3171$

we obtain for red $D_o = 21° 34'$, and for violet $D_\delta = 22° 22'$. This would give, as a result of dispersion, the width of the ring, as 48′, but to this we have to add the width of the source of light, the diameter of the moon, which in our case is 33′, giving us 1° 21′. This super-position of light explains the blurred or whitish appearance of the band between the red and blue.

Taking now the position of the moon at 11 p.m. Eastern Standard Time, or 16^h G. M. T. for January 3, as R. A. $6^h\ 30^m$, Dec. 27° 57′ and correcting for parallax; for α Orionis R. A. $5^h\ 50^m$, Dec. 7° 23′; also α Aurigæ R. A. $5^h\ 10^m$, Dec. 45° 55′, we find for the inner part of the ring or halo, the radius 22° 29′, and the other one 24° 19′, making the width of the color band some 1° 50′.

This would seem to indicate a slightly different value for the indices of refraction given above.

The above short note may draw some of the readers' attention, when such a moon halo is visible, not only to note the time and not too roughly, but to observe also whether one or other well-known star lies in or on the band whereby its radius may be found.

Accurate measures of halos are none too numerous, and additional measures are welcome.

Otto Klotz.

Dominion Observatory,
Ottawa, Canada,
January 6, 1912.

NOTES FROM THE METEOROLOGICAL SERVICE

Summary Report of the Weather in Canada

October

Temperature — In British Columbia the mean temperature for October differed very little from average. In Alberta there was a deficiency of about 2°, except at Edmonton, where the difference from normal was very slight. In Northern Saskatchewan there was a positive difference from normal amounting to 2° or less, while in the southern portions of the province, negative departures of equal value were reported. The mean temperature of the province of Manitoba, as a whole, showed a positive departure from normal of a little more than 1°. Through New Ontario mean temperatures were slightly below average, and in the Ottawa Valley and many of the eastern counties, slightly above average. Temperatures in the Eastern Townships were approximately normal for the month, while along the St. Lawrence the average was exceeded by 1° at Quebec and by 2° at Montreal. Over the greater part of the Maritime Provinces the temperrture was from 1° to 2° lower than average.

Precipitation — Throughout the province of British Columbia there was a deficiency of rain during October, the differenc from average being in many cases very large. The rainfall in southwestern Alberta was very little below normal, but over the rest of the province the deficiency was considerably greater. In the northern sections of Saskatchewan less than the usual amount of rainfall was recorded, but in the central and eastern districts precipitation was plentiful, as it was also in Manitoba. In New Ontario and in the Ottawa Valley there was a moderate deficiency, but throughout the remainder of Ontario there was an excess of approximately 20 per cent. There was a general lack of rain in

the Province of Quebec during the month, the deficiency amounting in most cases to one-third of the average, and in some cases to one-half. In the Maritime Province the precipitation was very slight, and in some counties almost amounted to a drought, scarcely one-fifth of the normal amount being registered in some places.

NOVEMBER

Temperature — The mean temperature of the month was lower than the normal over the whole of British Columbia. The difference from normal, while not great on Vancouver Island or the coast, ranged between 6° and 10° in the interior. In the Western Provinces the mean temperature ranged from 4° to 11° below the average. In Manitoba the lowest mean temperatures were, generally speaking, found in the western portions of the province. At Winnipeg it was nearly nearly 7° below the twenty-five year average. In the northerly parts of Alberta and Saskatchewan the difference from normal was least, while in southern Saskatchewan negative departures were over 10°. Weather conditions in the Lake Superior districts of Ontario were very similiar to that experienced in Manitoba; in the Ontario peninsula mean temperatures ranged from 2° to 4° below the average of the preceding 25 years. Mean temperatures for the month showed an average negative departure of about 2° in the province of Quebec, and the same holds true of the Maritime Provinces, although in the southwestern portion of Nova Scotia the normal was nearly maintained.

Precipitation — Snow fell during the month in all parts of the Dominion. In British Columbia the normal precipitation was largely exceeded during the month, a very heavy fall of snow occurring over the lower mainland and on Vancouver Island. There was a considerable deficiency in the Western Provinces, and also locally in Ontario and Quebec. Throughout the greater part of the latter two provinces, however, the precipitation was above the average. In the Maritime Provinces the precipitaion was largely in excess of the normal for the month.

Temperatures for October and November, 1911

Station	October		November	
	Highest	Lowest	Highest	Lowest
Yukon				
Dawson	54	4	30	-34
British Columbia				
Atlin	54	16	44	-14
Agassiz	71	19	63	12
Barkerville	68	14	40	-24
Kamloops	88	19	54	- 8
New Westminster	71	33	52	9
Prince Rupert	68	34	56	12
Vancouver	74	34	52	10
Victoria	66	34	56	14
Western Provinces				
Battleford	82	10	53	16
Broadview	79	7		
Calgary	74	14	51	21
Carman	73	13		
Edmonton	79	11	51	24
Medicine Hat	80	14	55	-26
Minnedosa	73	8	47	-23
Moose Jaw	84	9	48	22
Oakbank	68	12	43	21
Portage la Prairie	74	10	49	-19
Prince Albert	82	4	54	-24
Qu'Appelle	79	7	46	-18
Regina	79	5	47	35
Swift Current	80	14	50	20
Winnipeg	73	13	51	-15
Ontario				
Agincourt	73	25	60	13
Aurora	68	25	60	6
Bancroft	71	17	57	- 2
Barrie	66	28	60	7
Beatrice	68	23	62	- 5
Birnam	66	28	65	14
Bloomfield	70	25	60	10
Brantford	70	26	66	7
Bruce Mines	69	17	55	1
Chatham	75	22	64	11
Clinton	66	29	64	15
Cottam	70	20	64	9
Gravenhurst	66	25	61	- 1
Guelph	67	26	65	9
Haliburton	69	20	59	- 7
Hamilton	72	35	67	17
Huntsville	73	25	60	0
Kenora	64	8	38	-15
Kinmount	66	19	59	-10
Kingston	72	27	58	11
Lakefield				
London	70	28	62	13
Lucknow	69	27	62	11
Madoc	72	23	59	4
Midland			48	15
North Gower	75	20	72	5
Otonabee				
Ottawa	70	24	60	7
Owen Sound				
Paris	69	28	64	14
Parry Sound	66	24	63	4
Peterboro'	70	25	60	4
Port Arthur	72	13	44	4
Port Burwell	68	28	63	9
Port Dover	71	25	62	12
Port Stanley	69	26	60	13
Ronville	62	17	62	3
Sarnia				
Southampton	69	32	70	12
Stonecliffe	70	15	60	1
Stony Creek	74	27	68	16
Stratford	74	26	62	11
Toronto	75	27	62	18
Uxbridge	65	27	59	5
Wallaceburg	69	24		
Welland	70	25	64	16
White River	70	4	38	22
Quebec				
Brome	68	17	67	8
Father Point	63	22	63	14
Montreal	66	27	62	10
Quebec	65	23	56	9
Sherbrooke	67	23	65	9
Maritime Provinces				
Charlottetown	66	28	56	14
Chatham	64	22	64	7
Dalhousie	65	24	46	7
Fredericton	71	23	61	7
Halifax	68	26	59	20
Moncton	66	18	64	10
St. John	65	27	58	16
St. Stephen	73	17	63	6
Sussex	67	20	63	9
Sydney	70	26	60	15
Yarmouth	66	28	59	24

Earthquake Records by the Milne Seismograph

TORONTO

R. F. Stupart, Director.

P.T. = Preliminary Tremors. L.W. = Large Waves. Time is Greenwich Civil Mean Time, 0 or 24 h = midnight.

No.	Date 1911	P.T. Comm.	L.W. Comm.	Max.	End.	Max. Amp.	Durat.	Remarks
		h m	h m	h m	h m	mm.	h m	
1039	Oct. 6	10 21·8	10 26·4 10 30·6	10 35·2	13 50·4?	5·5	3 28·6	Eq. reported from [Port au Prince [Hayti.
1040	" 10	13 24·7	13 27·3) 13 29·7)	13 31·8	14 48·7	7·7	1 24·0	Moderate
1041	" 13	3 3·5	V. 3 11·3 V. 3 16·2	3 32·3	4 52·7	0·5	1 49·2	Eq. and Tidal Wave [reported from Gulf [of California.
1042	" 14	12 57·8 V. 13 4·2	13 9·1	13 15·5	14 0·4	0·4	1 2·6	Increase of thicken-[ing at 13h 44.8.
1043	" 14	16 56·6	V. 17 2·3 V. 17 7·2	17 15·5	18 39·5?	1·5	1 43·5	
1044	" 15	0 26·8		0 28·6	0 45·8	0·1	0 19·0	[seismic
1045	" 15	18 31·4			18 35·2	0·1	0 3·8	Doubtful as to being
1046	" 15	23 50·7			24 0·7	0·05	0 10·7	Doubtful as to being
1047	" 16	0 10·0	0 12·8	0 14·0	0 50·6	0·2	0 40·6	[seismic
1048	" 17	10 17·6		10 59·2	11 18·7	0·2	1 01·1	Extend. thickenings
1049	" 20	18 13·0		18 44·0	19 35.0	0·2	1 22·0	
1050	" 26	14 29·8	14 34·2	14 35·2	15 6·5	2·0	0 36·7	
1051	" 29	18 10·3 V. 18 19·1	18 23 6) 18 35·2)	18 39·5	19 47·0?	0·5	1 36·7	Prolonged L. W.
1052	Nov. 1	9 41·3	9 44.8?	9 46·2	10 26·0	0·4	0 44·7	Eq. report. from Ni-[caragua, at 3.40
1053	" 7	6 12·8			6 13·8	0·05	0 1·0	
1054	" 13	Air tremors	16 44·5?	17 0·1	18 02·6?	1·1		Marked by A.T.
1055	" 18	7 46·4	7 51·1 7 54·3	7 58·0	9 15·5	1·0	1 29·1	
1056	" 19	15 4·0			A.T.	0·1		[seismic Doubtful as to being
1057	" 20	13 30·0			13 39·0		0 3·0	A. T. going on.
1058	" 20	A.T.	14 3·6	14 10·4	14 56·5?	1·7	0 52·8?	Eq. report. from St.
1059	" 21	18 52·4		18 52·9	19 0·6	0·3	0 8·2	[Thomas, W. Indies. (seis.
1060	" 22	10 26·7			10 33·2	0·2	0 6·5	Doubtful as to being
1061	" 25	19 33·3	19 48·6	19 49·0 50·8	20 33·9	0·5	1 00·6	P.T's. continued a [long time.

Period 14·7 seconds. 1 mm. = 0″·64.

VICTORIA, B. C.

E. B. REED, SUPERINTENDENT.

No.	Date 1911		P.T. Comm. h m	L.W. Comm. h m	Max. h m	End h m	Max. Amp. mm.	Durat. h m	Remarks
1055	Oct.	6	10 35·6)	10 43·3)					Eq. report. from (Port au Prince (Hayti.
			10 36·4)	10 44·2)	10 53·1	11 53·2?	1·4	1 17·6	
				B 10 48·4					
1056	"	10	13 29·6	13 43·1	13 54·7	14 53·3	1·1	1 23·7	
				B 13 48·9					
1057	"	13	2 48·6	3 4·1)	3 7·1)	4 13·5?	0·5	1 24·9	Tid. W. and Eq. (East Side Gulf (of California.
		V.	2 54·8	3 6·4)	3 8·1)				
			12 41·8)	12 58·9)					
1058	"	14	V. 12 51·3)	13 8·0)	13 14·0	14 5·2	0·4	1 23·4	Inc. of thicken-ing at 13h 17m12.3.
				B 13 12·2					
1059	"	14	16 44·3	16 51·0	17 5·7	18 15·1	1·0	1 30·8	
1060	"	15	0 27·1		0 31·7	0 30·1	0·1)	0·0	
1061	"	15	23 47·9	23 55·0		23 58·7	0·2)	10 8	No marked max.
1062	"	16	0 7.8			0 13·2	0·1)	5·4	No marked max.
1063	"	17	10 5·1?			10 39·6	0·05	0 34·5	
1064	"	20	18 5·4	18 10·9	18 12·9	18 55·0	0·3	0 49·6	
1065	"	20	18 23·2	18 33·1	18 35·7	19 43·4	1·2	1 20·2	Well defined.
1066	Nov.	1	9 46·9	9 56·1	10 0·0	10 34·8	0·4	0 47·9	Eq. report. from (Nicaragua.
1067	"	12	16 25·7	16 32·0	16 48·9	18 17·1?	0·8	1 51·4	
1068	"	13	7 39·8	7 53·1	7 55·9	8 47·5	1·3	1 07·7	
1069	"	16	14 45·0	14 45·6	14 46·0	14 55·4	1·3	0 10·4	Sud. vib. boom (came gra. to r'st
1070	"	20	13 44·3			13 46·5	0·05	0 2·2	
1071	"	20	14 4·1	14 15·3	14 22·5	15 20·3	0·8	1 22·2	Eq. felt in West (Indies at 5.45.
1072	"	21	18 48·9			18 53·0	0·05	0 4·7	
1073	"	25	19 44·0		19 46·0	19 50·3	0·3	0 5·7?	

Period 15 seconds. 1 mm. = 0·76

J. V.

MAGNETIC OBSERVATIONS

The months of October and November are remarkable for the large number of calm days and the absence of large disturbance, and therefore the small monthly range in both declination and horizontal force.

The only disturbance of note occurred on the 10th and 11th of October and its greatest influence was on the horizontal force causing it to range through 298γ.

During this period auroræ were seen in all parts of Canada, several of which were recorded as being particularly brilliant.

ERRATA—A correction of −4′·2 is to be applied to declination values as published for August, and of −3′·7 for September.

Declination

Month	Mean of Month	Max.	Date	Min.	Date	Monthly Range	Amplitudes—Mean Daily	
							From hourly readings	From Means of Extremes
1911	° ′	° ′		° ′		° ′	° ′	° ′
Oct.	6 10·6	6 28·1	17	5 51·2	11	0 36·9	0 8·0	0 14·2
Nov.	6 11·3	6 35·4	14	5 54·2	8	0 41·2	0 5·4	0 11·7

Horizontal Force—C.G.S. Units

Oct.	·16188	·16222	10	·15924	11	·00298	·00030	·00056
Nov.	·16104	·16240	11	·16149	14	·00091	·00024	·00038

Inclination

Month	Mean
	° ′
October	74 39·7
November	74 39·3

ASTRONOMICAL NOTES

POSSIBLE PHASE-RELATIONS BETWEEN THE PLANETS AND SUN-SPOT PHENOMENA—A careful study of the detailed figures underlying the tables in this paper, leaves the author unable to support the theory of a real planetary effect. . . . . The foregoing notes are mainly negative in character, suggesting that the case for planetary effects on sun-spot phenomena is "Not proven." The hope with which the investigation was originally undertaken has not, however, been abandoned. The writer's view is still that the dynamical effects of planets upon what may be an atmosphere of very uncertain stability should be manifested in some solar phenomena. Sufficient data are not yet accumulated to smooth out the effects of the far more efficient forces which cause the great periodic outbursts of solar activity, and no certain conclusions seem as yet to be within the reach of the investigator.—*Monthly Notices, R.A.S.*, Vol. LXXII., No. 1.

THE STRUCTURE OF THE UNIVERSE. — In *Ast. Nach.* 4536 Mr. Frank Very, of Massachusetts, has a remarkable article "On the White Nebular Galaxies," in which he endeavors to make an estimate of the distance of the nebulæ. In the course of the article he arrives at a value of the dimensions of the Milky Way from the assumption that Nova Persei was actually in the Galaxy, and hence finds that its outer diameter can hardly exceed $1{\cdot}2 \times 10^{18}$ km., though there may be a shell of sparsely distributed stars encompassing this. From this he goes on to estimate the distance of the Andromeda Nebula—first on the assumption that it is a Galaxy of the same dimensions as the Milky Way, and secondly from the assumption that the Nova in Andromeda of 1885 was actually in the nebula, assuming also a value for its intrinsic brightness. The two methods give rather different values, one being four-tenths the other; but after some

further considerations, Mr. Very arrives at the result that the Andromeda nebula is 1600 light-years distant, and that the white nebulæ are galaxies or distan tuniverses, the smallest and faintest being at a distance of one million light-years.

Royal Meteorological Society.—The Council of the Royal Meteorological Society have awarded the Symons Gold Medal to Professor Cleveland Abbe, of the United States Weather Bureau, in recognition of the valuable work which he has done in connection with meteorological science. The medal will be presented at the Annual Meeting of the Society on January 17, 1912.—*Observatory*, No. 442.

The Imperial Academy of Japan has awarded a medal and testimonial to Dr. Kimura for the discovery of the term in the latitude variation which is now ordinarily known as the Kimura-term. This term is annual in period, is independent of the longitude of the observing station, and corresponds to a shift of the centre of inertia of the earth of between four and five feet either way from its mean position. It is annual in period, and no satisfactory explanation of its cause has yet been given. One hypothesis which has been advanced endeavors to explain it as a meteorological effect due to the increase of the layer of ice and snow at one pole, accompanied by the corresponding and simultaneous diminution of this layer at the opposite pole. But the maximum period in the Kimura-term does not come at the proper epoch to make this hypothesis an acceptable one. -*Publications Astronomical Society of the Pacific*, 139.

Stellar Motion and Spectral Type.—The study of the systematic motions of the stars has engrossed much attention in recent years, Professor Kapteyn taking the lead with his announcement of the two general drifts which could be detected when the motions were analysed. This announcement was confirmed and extended by the work of Mr. Eddington, Professor Schwarzschild, and others. Last year Mr. Hough and Dr. Halm examined the radial motions of the stars, derived from spectroscopic observations, and found that these too showed anomalies

such as the two-stream theory would lead us to expect. Dr. Halm has recently (*Month. Not. R.A.S.*, 1911, June) returned to the subject and arranged the evidence in a manner which makes the conclusions more evident. After eliminating the solar motion he finds preponderance of motion in the direction of the vertices of the two drifts. The average motion taken without regard to sign is twenty-six kilometres per second in these regions, and goes down to fifteen kilometres per second at intermediate points. Dr. Halm's paper also contains further confirmation of the result already announced by Kapteyn and others, that a star's velocity increases as its spectral type grows more advanced. Thus the Orion type, which is supposed to consist of very large and heavy stars, in a very early stage of development, has a mean motion of six kilometres per second in the line of sight; the Sirian type has eleven kilometres, while for later types the mean motion goes up to eighteen kilometres. The advantage of the spectroscopic method is that it is independent of distance; it is particularly valuable in the case of the Orion stars, which are so remote that their transverse velocity is difficult to ascertain.

Mr. Eddington, in a paper read before the British Association reprinted in the *Observatory* for October last, refers to the above result as "one of the most startling in modern astronomy." He proceeds:—"For the last forty years astrophysicists have been studying the spectra and forming their systems by which they arrange the stars in order of evolution. . . . If this result is right we have a totally different criterion by which the stars are arranged in the same order. If it is really true that the mean motion of a class of stars measures its progress along the path of evolution, we have a new and most powerful aid to the understanding of the steps of stellar development."—*Knowledge*, No. 521.

Radio-Activity.—It is now accepted that the α particles emitted by radio-active elements are atoms of the gas helium. In the case of niton (radium emanation) this is capable of spectroscopic verification.—Charles W. Raffety, in *Knowledge*, No. 520.

J. R. C.

BOOK REVIEWS

The Sun. CHARLES G. ABBOT, S. M., Director Smithsonian Astrophysical Observatory. New York: D. Appleton & Co., 1911.

Few, if any, scientific investigations have in recent years been more fruitful of results than those whose object is the obtaining of exact information regarding the conditions that exist in the sun and their relation to terrestrial phenomena. The classical works of Secchi and Young on the sun, in view of the important discoveries of Deslandres, Hale, Langley, Adams, and Abbot, to mention the names of a few of the more prominent workers in this field, do not to-day afford an adequate statement of our knowledge touching the great ruler of our system. The appearance of the work of the distinguished director of the Smithsonian Observatory is timely, and the work itself is in the fullest sense of the expression up-to-date. A well written chapter gives in an interesting manner the essential facts in regard to the solar system. The refined and highly differentiated instruments are described and the methods of investigation outlined. The positive information thus reached is carefully presented, and discussed in relation to the outstanding questions of the conditions in the solar envelopes, the nature of sun spots, faculæ and granulation, the state in which the matter of the sun as a whole exists, the source of the sun's heat, and the influence of the sun on climate and on plant life. One of the most interesting chapters is that devoted to the consideration of the devices for the utilization of the sun's energy. The concluding chapter treats of the sun's place in the the system of the stars. Altogether, the work is an interesting and thoroughly scientific presentation of our actual knowledge of the sun, and it is commended to all who have any concern in astronomy and especially to those whose scientific curiosity has found a field of interest in the sun. δ.

PLATE XXXIV.

JOSEPH MILLER BARR

Died July 8, 1911, aged 54 years.

NOTES AND QUERIES

Communications are Invited, Especially from Amateurs. The Editor will try to Secure Answers to Queries.

JOSEPH MILLER BARR.

Joseph Miller Barr died in St. Catharines on Saturday, July 8, 1911, at the age of fifty-four. He was the son of the late James Barr, at one time a prosperous merchant of that city. For a long period his health had not been good, and at the time of his death he had been in the hospital six months.

During his entire lifetime, Mr. Barr was of a very studious disposition, and from his earliest years he showed great interest in astronomy. Letters on scientific subjects, written by him, were not unfrequently seen in the local papers, while his contributions have appeared in the *Astrophysical Journal* and especially in this JOURNAL.

Mr. Barr's chief activity was in the fields of variable stars and spectroscopic binaries, and he added to our knowledge of both of these subjects. Indeed he was one of the few amateurs in Canada who have made distinct contributions to astronomical science. His death will be widely noted with regret.

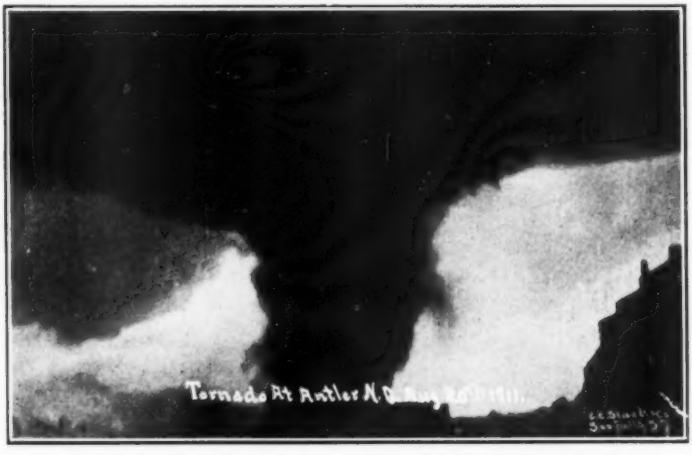
Mr. Barr was of a decidedly retiring nature, and while he freely prepared papers for the meetings of our Society, he could not be prevailed upon to go and read them in person.

The portrait presented herewith was taken some years ago and being a "tin-type" does not lend itself well to reproduction.

PHOTOGAPH OF A TORNADO.

The interesting photograph, reproduced herewith, was sent to the writer by Mr. D. Shirriff, of Brandon, Manitoba, who furnishes some particulars regarding it.

The tornado went across the south-west part of Manitoba and a portion of North Dakota, on August 20, 1911. The picture shows it passing near an elevator in Antler. The photographer first put his family in a cellar and then went out to take a "snap-shot" of the dark whirling cloud as it passed by. The



A Tornado, in North Dakota.

storm did much damage both in Manitoba and Dakota, several people and horses being killed and others badly injured. A boy who was carried upwards, and who afterwards died from his injuries, said that he saw the trees beneath him and a team of horses over him, from which one can imagine the awful nature of the phenomenon.

TELESCOPES FOR THE MEMBERS.

Nothing quickens the interest in astronomical matters so much as a direct study of the heavenly bodies themselves, and for that reason the Editor is glad to facilitate the acquiring or transfer of astronomical instruments by the members.

The accompanying cut is from a photograph of a five-inch refractor in possession of Mr. A. H. W. Cleave, of Ottawa, which he desires to dispose of. The instrument has an altazimuth and

MR. A. H. W. CLEAVE'S TELESCOPE.

also an equatorial mounting with driving clock. The object glass is of the latest Watson-Conrady type, made in 1909, of Jena glass, and the accessories are very complete.

The writer would be pleased to give further information.

ERROR IN "HANDBOOK" FOR 1912.

In the map of circumpolar stars two constellations are named Ursa Major. That nearer the Pole should, of course, be Ursa Minor.

C. A. C.

INDEX TO VOLUME V.

* Indicates Book Reviews

A

*Abbot, Charles G., The Sun, 448.

a Geminorum, *W. E. H.*, 137.

Aitken, R. G., Life on Other Worlds, 291.

Ancient and Modern, Calendars, *Albert D. Watson*, 172.

* Annuaire Astronomique de l' Observatoire Royal de Belgique, 1912, 239.

Astronomical and Astrophysical Society of America, *C. A. Chant*, 327.

Astronomical Notes, 90, 148, 232, 282, 346, 445.

Astronomical Society of India, 95.

Astronomy in Mexico, 285.

Astrophysics, Notes on, *J. S. P.*, 84; *b* Persei, *J. B. C.*, 137.

Audibility of the Aurora, C. A. C. 154.

Aurora, Mystery of the, C. A. C., 155.

B

Babylonian Astrology, E. W. Maunder, 148.

Book Reviews, 239, 448.

b Persei, *J. B. C.*, 137.

Brightness of the Night Sky, C. G. Abbot, 282.

Brooks' Comet, 284.

C

Calendars, Ancient and Modern, *Albert D. Watson*, 172.

Canals of Mars, E. M. Antoniadi, 348.

Cannon, J. B., Diameters of the Stars, 349; Note on φ Persei, 372; Orbit *b* Persei, 266.

Carson, P. A., Precise Measuring with Invar Wires; and the Measurement of Kootenay Base, 36.

Changes in Focus Produced by Plane Gratings, *Ralph E. DeLury*, 26.

Chant, C. A., Astronomical and Astrophysical Society of America, at Ottawa, 327; Great Modern Telescope, 309; Mars: The Planet of Mystery, 408; Notes and Queries, 92, 154, 240, 286, 349, 449.

Classification of the Chemical Types of Stars, Note on the, *W. Balfour Musson*, 125.

Comets, Brooks', 284; Halley's in Ceylon, 148; Regarding the Results of Observations of Halley's, D. Eginitis, 149.

D

Darwin's Tidal Theory, *A. J. Dempster*, 185.

Death of Mrs. Fleming, C. A. C., 243.

DeLury, A. T., Evolution of Worlds, 1.

DeLury, Ralph E., A Device for Guiding the Image Produced by a Coelostat Telescope, 33; Changes in Focus Produced by Plane Gratings, 26; Errors in the Measurement of Spectral Line Displacements, 384.

Dempster, A. J., Darwin's Tidal Theory, 185.

Determination of Orbits, *L. B. Stewart*, 97.

Developments in Astronomy, Some Recent Interesting, *J. S. Plaskett*, 245.

Device for Guiding the Image Produced by a Coelostat Telescope, *Ralph E. DeLury*, 33.

Diameter of the Stars, *J. B. Cannon*, 349.

Distribution of Globular Star Clusters, H. C. Plummer, 152.

E

Earthquake Records at Toronto and at Victoria, B.C., *J. Y.*, 89, 146, 230, 280, 344, 442.

Eclipse Cycles, W. H. S. Monck, 117.

Errors in the Measurement of Spectral Line Displacements, *Ralph E. DeLury*, 384.

Evolution of Worlds, *A. T. DeLury*, 1.

Examination Answers, C. A. C., 156, 244.

F

Fleming, Death of Mrs., C.A. C., 243.

Formation of Sunspots, Influence of Planets on the, A. Schuster, 149.

G

Geminorum, α, 137; Orbit of σ, W. E. H., 200.

Globular Star Cluster, Distribution of, H. C. Plummer, 152.

Gold Medal, R.A.S.C., C. A. C., 244.

Goodacre's Map of the Moon, 156.

Great Modern Telescopes, *C. A. Chant*, 309.

H

Halley's Comet in Ceylon, 148; Regarding the Results of Observations of, D. Eginitis, 149.

Halo, A, *O. K.*, 437

Harper, W. E., Orbit of ρ Orionis, 16; Orbit of σ Geminorum, 200; Spectroscopic Binary 7 Camelopardalis, 112.

Heat and Light Meteorites, Rev. M. Davidson, 233.

* History of Science, List of Books on the, 240.

I

Influence of Planets on the Formation of Sun-spots, A. Schuster, 149.

Invar Wires, Precise Measuring with, *P. A Carson*, 36.

J

Jenkins, G. Parry, Plea for the Reflecting Telescope, 59.

Joseph Miller Barr, C. A. C., 449.

Jupiter, T. E. R. Phillips, 284; in a Large Telescope, T. E. R. Phillips, 347.

K

Kepler, (Poem), A. D. W., 285.

Kinetic Theory of Gravitation, Charles F. Brush, 151.

Klotz, Otto, A Halo, 437; Magnetic Observations, 138; Secular Change, 141; Sterographic Projection Tables, 205; Terrestrial Magnetism, 157.

Kootenay Base, Measurement of, *P. A. Carson*, 36.

L

Life on Other Worlds, *R. G. Aitken*, 291.

*List of Books on the History of Science, 240.

M

Magnetic Observations at Agincourt, 88, 147, 228, 281, 345, 444.

Magnetic Observations at Ottawa, 138.

Mars: the Planet of Mystery, *C. A. Chant*, 408.

Measurement of Spectral Line Displacements, Errors in the, *Ralph E. DeLury*, 384.

Measuring with Invar Wires; and the Measurement of Kootenay Base, Precise, *P. A. Carson*, 36.

Mechanical Production of Streamers seen in the Solar Corona, J. A. Miller, 233.

Meetings of Society, at Toronto, 76, 128, 216, 418; at Ottawa, 78, 131, 217, 425; at Hamilton, 81, 221, 430; at Peterborough, 82, 135, 431; at Regina, 432; at Guelph, 222, 435.

Migrating Stars, 237.

Monck, W. H. S., Eclipse Cycles, 117.

Motion of Calcium Vapor Over Sun-spots, Charles E. St. John, 235.

Motion of Certain Stars in Space, 148.

Musson, W. Balfour, Note on the Classification of the Chemical Type of Stars, 125.

Mystery of the Aurora, C. A. C., 155.

N

Nature of Inertia, H. A. Wilson, 237.

Newspaper Astronomy, 95.

New Stars, Professor Bickerton, 91.

Note on the Classification of the Chemical Type of Stars, *W. Balfour Musson*, 125.

Note on φ Persei, *J. B. Cannon*, 372.

Notes from the Dominion Observatory, 84, 137, 339, 437.

Notes from the Meteorological Service, 85, 143, 225, 277, 341, 439.

Notes and Queries, 92, 154, 286, 349, 449.

Nova Lacertæ, 234.

Nugent, D. B., Personal Errors of Bisection in Meridian Circle Work, 272.

Nutation, J. A. Hardcastle, 282.

O

Observations on the Aurora, *Andrew Elvins*, 242.

October Sky, Constellation of the, Hector Lang, 433.

Orbit of *b* Persei, *J. B. Cannon*, 266.

Orbit of γ Orionis, *W. E. Harper*, 16.

Orbit of σ Geminorum, *W. E. Harper*, 200.

Orbit of ω Ursæ Majoris, *T. H. Parker*, 377.

Orbits, Determination of, *L. B. Stewart*, 97.

Orbits of the Spectroscopic Components of *d* Bootis, *W. E. Harper*, 315.

Other Worlds, Life on, *R. G. Aitken*, 291.

P

Parker, T. H., Orbits of ω Ursæ Majoris, 377.

Personal Errors of Bisection in Meridian Circle Work, *D. B. Nugent*, 272.

Photograph of a Tornada, C.A.C., 449.

Place of Comet in Cosmogony, 232.

Planet of Mystery, Mars, *C. A. Chant*, 408.

Plaskett, J. S., Notes on Astrophysics, 84; Some Recent Interesting Developments in Astronomy, 245.

Plea for the Reflecting Telescope, *G. Parry Jenkins*, 59.

Possible Phase-relations between the Planets and Sun-spot Phenomena, 445.

Precise Measuring with Invar Wires; and the Measurement of Kootenay Base, *F. A. Caison*, 30.

R

Radio-Activity, C. W. Raffety, 447.

R.A.S.C. Gold Medal, C. A. C., 244.

Reflecting Telescope, Plea for the, *G. Parry Jenkins*, 59.

Report of Weather in Canada, R. F. S., 85, 143, 225, 277, 341, 439.

Rotation of Venus, 285.

Royal Meteorological Society, 446.

S

Satellites of Mars, Professor Lowell, 151.

Secular Change, *O. K.*, 141.

Shakespeare, the Astronomy of, J. A. Paterson, 435.

Some Recent Interesting Developments in Astronomy, *J. S. Plaskett*, 245.

Spectroscopic Binary 7 Camelopardalis, *W. E. Harper*, 112.

Spectroscopic Components of *d* Bootis, Orbits of the, *W. E. Harper*, 315.

Spectroscopic and Visual Binaries: An Outline of Work Done in This Field and an Indication of Its Importance, *Reynold Young*, 355.

Stars, Distances of the, F. A. McDairmid, 426.

Star Streams, 90.

Stellar Distribution and Movements, A. S. Eddington, 346.

Stellar Motion and Spectral Type, 446.

Sterographic Projection Tables, *Otto Klotz*, 205.

Stewart, L. B., Determination of Orbits, 97.

Structure of the Universe, F. Very, 445.

Sun, the, Charles G. Abbot, 448.

T

Telescopes for the Members, C. A. C., 450.

Temperature Tables, 87, 145, 227, 279, 343, 441.

Terrestrial Magnetism, *Otto Klotz*, 157.

Theory of Grazing Collisions, M. Davidson, 283.

Tidal Actions, 238.

Total Solar Eclipse of April 28, 232.

V

Vatican Observatory, 96.

W

Watson, Albert D., Calendars, Ancient and Modern, 172; Kepler, 285.

Wolf's Comet, 237.

Worlds, Evolution of, *A. T. DeLury*, 1.

Y

Young, J., Earthquake Records Toronto and Victoria, 89, 146, 230, 280, 344, 442.

Young, Reynold, Spectroscopic and Visual Binaries: An Outline of Work Done in this Field and an Indication of Its Importance, 355.